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Solving the "Tragedy of the Commons":
An Alternative to Privatization*

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Comments welcome.

(ABSTRACT)

This paper formulates the "tragedy of the commons" in game-theoretic terms. The source of this problem is that of moral hazard, wherein the unobservable behaviour of agents who have an incentive to violate a trust induces their anti-social action. Since the outcome of the collective behaviour of all agents is observable, it is possible to devise a rule which penalizes each agent by a sum exceeding the gain which any agent would realize by his or her independent anti-social action. It is shown that an appropriate rule involving collective punishment will provide an incentive structure which induces each rational agent to behave in a socially responsible manner, so that in equilibrium, such penalties will not have to be exercised.

1. INTRODUCTION

The biologist Garret Hardin first coined and popularized the aptly chosen phrase, "the tragedy of the commons," to describe a class of situations in which collective ruin befalls a group of individually rational agents¹. In Hardin's original parable, a group of herdsmen allow their respective herds of cattle to graze on a commons pasture. The grazing on the commons must somehow be rationed if the commons is to remain a sustainable resource, since the total size of the herdsmen's flocks exceeds the carrying capacity of the commons. Overgrazing will result in the depletion of the commons and its destruction as a renewable resource.

Historically, to cope with the problem of managing the commons in their collective interest, the solution sought by herdsmen involved each undertaking to refrain voluntarily from exceeding some prescribed quota with respect to the utilization of the commons.

If we denote by x the maximum number of cattle that the commons could sustain, then if there were n symmetric herdsmen, an equitable rationing scheme would assign each herdsman a grazing quota of x/n cattle.

Such schemes have historically been unsuccessful for three reasons. First, because each herdsman had an incentive to exceed his prescribed quota, the seeds of instability of verbal agreements are manifest. The second factor contributing to the failure of voluntary rationing schemes is the anonymity of the cheating herdsman, which eliminates his vulnerability to retaliatory measures by the compliant herdsmen. Finally, the symmetry of the herdsmen implies that what is attractive to one is attractive to all so that all herdsmen will succumb to the temptation to exceed their respective grazing quotas. The conjunction of these three elements—the incentive to overgraze, anonymity of those who do so, and symmetry of the agents, combine to render a voluntary quota system unworkable.

As noted above, the contexts in which the tragedy of the commons phenomenon manifests itself are many and varied. One uncommonly common example is that of a common fishery. In this setting, all fishermen who share the facility are tempted to overexploit the stock of fish, with the result that ultimately the fish will disappear to their collective detriment.

In section 2, we present a formal model of the tragedy of the commons, and describe the "market solution," which replaces common ownership by private ownership of the commons pasture. The privatization solution was first proposed by H. Scott Gordon. This way of solving the tragedy of

¹ G. Hardin, "The Tragedy of the Commons," *Science* 162, pp.1243-48, reprinted in H. E. Daly, Ed., *Toward A Steady- State Economy*. W.H. Freeman and Company, (San Francisco, 1973).

² H. Scott Gordon, "The Economic Theory of a Common-Property Resource: The Fishery," *Journal of Political Economy*. April 1954, reprinted in

the commons does not have universal appeal, inasmuch as the institution of private ownership is not regarded by all as a form of social organization which is necessarily superior to that of public ownership. This is the motivation for the alternative proposal which appears in section 3—one which preserves the public ownership of the commons and yet averts the disaster of overgrazing. Our proposal is in the spirit of the "mechanism design" literature which seeks to induce rational self-interested individuals to act in a socially desirable manner. Section 4 provides a summary of the results.

2. THE MARKET SOLUTION

We shall illustrate the logic of the market solution to the tragedy of the commons problem in a simple model.

Let $N=\{1,\dots,n\}$ denote the set of n symmetric herdsman;

$S^i=\{C,E\}$ denotes the strategy set of the i th herdsman, where C represents the strategy of complying with a quota of grazing x/n cattle, and E represents the strategy of exceeding the quota by grazing $x/n + 1$ cattle;

s_i =the actual level of grazing selected anonymously by the i th herdsman, i.e., S_i is either C or E ;

$P_i(s_1,\dots,s_n)$ =the payoff to herdsman i from a particular n -vector of strategies, i.e., when all herdsman select their respective grazing levels.

Now suppose that the carrying capacity of the commons is x , so that if the total number of cattle grazed on the commons does not exceed x , the commons would remain a sustainable resource. However, suppose that if the grazing level exceeds this critical threshold, it would result in a collectively ruinous outcome, inasmuch as the commons would become irreversibly depleted. However-- and this aspect lies at the heart of the "tragedy of the commons" parable—it would be individually profitable for a typical anonymous herdsman to deviate unilaterally from strategy C to E , given that all other herdsman are adopting strategy C .

In other words, the strategy vector wherein all herdsman behave in a socially responsible manner and each grazes only x/n cattle does not represent a Nash equilibrium, i.e., a vector of mutually best-response strategies, since each herdsman would be tempted to exceed his prescribed quota, notwithstanding the costs that would thereby be imposed on the other $n-1$ herdsman—costs which could well exceed the gain to the overgrazing herdsman.

For $i=1,\dots,n$, define $s_i^*=C$ and $s_i=E$.

Denote by (s_{-i}, S_i) the n -vector of strategies in which all agents except i adopt C while i adopts strategy E ; and denote by (s^*) the n -vector of strategies in which all agents adopt strategy C .

The tragedy of the commons is characterized by the following two conditions:

$$(1) P_i(s^*_{-i}, s_i) > P_i(s^*)$$

$$(2) \sum_{j \in N \setminus i} P_j(s^*) - \sum_{j \in N \setminus i} P_j(s^*_{-i}, s_i) > P_i(s^*_{-i}, s_i) - P_i(s^*)$$

Condition (1) states that each agent would have an incentive to deviate unilaterally from C to E, given that others are complying with their grazing quota. Condition (2) states that the gain which could be realized by any representative agent, say i , through deviating from strategy C to E would, from society's point of view, be more than offset by the loss that this imposes on the other $n-1$ agents.

We are assuming implicitly that the social optimum is one in which each herdsman complies with his quota, i.e. all herdsmen adopt strategy C, i.e., the socially optimal strategy vector is s^* . This can be stated more formally as condition (3):

$$(3) \underset{s \in X}{\text{ARGMAX}} \sum_{i \in N} P_i(\cdot) = s^*$$

With transferable utility and side-payments, the social outcome arising from s^* could potentially Pareto-dominate any other outcome. If the criterion proposed by Kaldor³ and Hicks⁴ for judging the desirability of a social change is adopted, namely, determining whether it admits a potential Pareto-improvement, so that those who stand to gain from the social change could fully compensate those who stand to lose and still themselves remain better off, then it could be claimed that s^* generates the socially optimal outcome.

Of course in a cooperative game setting with binding agreements, a prospectively deviant herdsman could be bribed by the other herdsmen, on mutually beneficial terms, to refrain from deviating from C to E. However, since binding agreements are ruled out in the setting of non-cooperative games, each rational agent would succumb to the temptation to deviate from C to E. The result would, of course, be disastrous.

How can this terrible outcome be prevented? The solution proposed appeals to the principle of "internalization of the externality" by means of privatization. This involves replacing common property by private property. A single owner of the pasture land will husband this resource and will ensure that overgrazing will not take place, since it would clearly be unprofitable to allow the number of grazing cattle to exceed the carrying capacity of the pasture. At the margin, an additional animal will be permitted to graze only so long as doing so yields a net profit, i.e., the monetary value of the adverse impact on

³ N, Kaldor, "Welfare Propositions and Intepersonal Comparisons of Utility," *Economic Journal*. September 1939, pp.549-52.

⁴ J.R. Hicks, "The Foundations of Welfare Economics," *Economic Journal*. December 1939, pp.696-712.

the existing herd of grazing cattle is exceeded by the monetary value of the beneficial effect upon the marginal cow entering the pasture.

If x is the joint-profit maximizing size of the collective herd of cattle to be grazed by the herdsmen, then x is precisely the size of herd which a single owner of the commons pasture will graze. The problem of implementing this solution through reliance upon the independent decisions of the herdsmen disappears in the setting of a private owner of the commons.

As already noted above, this market solution has been proposed by H. Scott Gordon in the setting of a fishery to solve the problem of overexploitation of its stock.

3. THE ALTERNATIVE SOLUTION

How can an appropriate incentive structure be constructed which will motivate the herdsmen in our parable to refrain from overgrazing the commons pasture, even though each can do so without detection? The principle which underpins our proposed alternative to privatization is that of "incentive compatibility." Incentive compatibility can be created by making it individually most profitable for each herdsman to graze exactly x/n cattle. How can this environment be implemented?

Consider the following scheme. Each herdsman enters into the following contract with the same outside agent. Should there be evidence that overgrazing has occurred, each herdsman will forfeit his entire herd, regardless of his personal innocence or guilt. In other words, such forfeiture of assets will occur even if only a single herdsman exceeded his quota by one cow while all others complied with the established limit.

The principle of collective punishment, upon which this proposal is based, may appear morally offensive to some. However, what should be emphasized is that, in fact, the collective punishment would not be carried out; for each herdsman would find that grazing x/n cattle is the (weakly) dominant strategy. A herdsman would be worse off by grazing more than x/n cattle if all the others were complying with this limit, since he (as well as all the others) would forfeit his herd; and he would not be better off by overgrazing if one or more others were also overgrazing, since he would forfeit his herd in any event.

The appealing feature of this incentive compatibility scheme is that it would permit the institution of common property to be preserved, and by appropriately motivating the herdsmen to act in a socially responsible manner, there would be no need to carry out the morally repugnant threat of collective punishment. The threat of collective punishment will have served its function of preventing the herdsmen from self-destructive behaviour.

4. SUMMARY AND CONCLUSION

In coining the phrase "the tragedy of the commons", Garret Hardin referred to the explanation of the concept of "tragedy" provided by the eminent philosopher, A.N. Whitehead⁵:

The essence of dramatic tragedy...resides in the solemnity of the remorseless working of things.

Hardin notes that in the "tragedy of the commons"⁶.

Each man is locked into a system that compels him to increase his herd without limit--in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all.

Hardin's list of possible solutions to the tragedy of the commons consists only of some form of privatization, or of direct first-come-first-served rationing. To this list may now be added our proposed solution, based upon the threat of collective punishment for overexploitation of a common resource. Unlike more Utopian schemes which are based upon fundamental changes in human values or ideas of morality, our proposal has at least the virtue of preventing environmental self-destruction in a world inhabited by rational, self-seeking individuals.

⁵ A.N. Whitehead, Science and the Modern World. Mentor, (New York, 1948), p.17.

⁶ Hardin, op. cit., p.138.