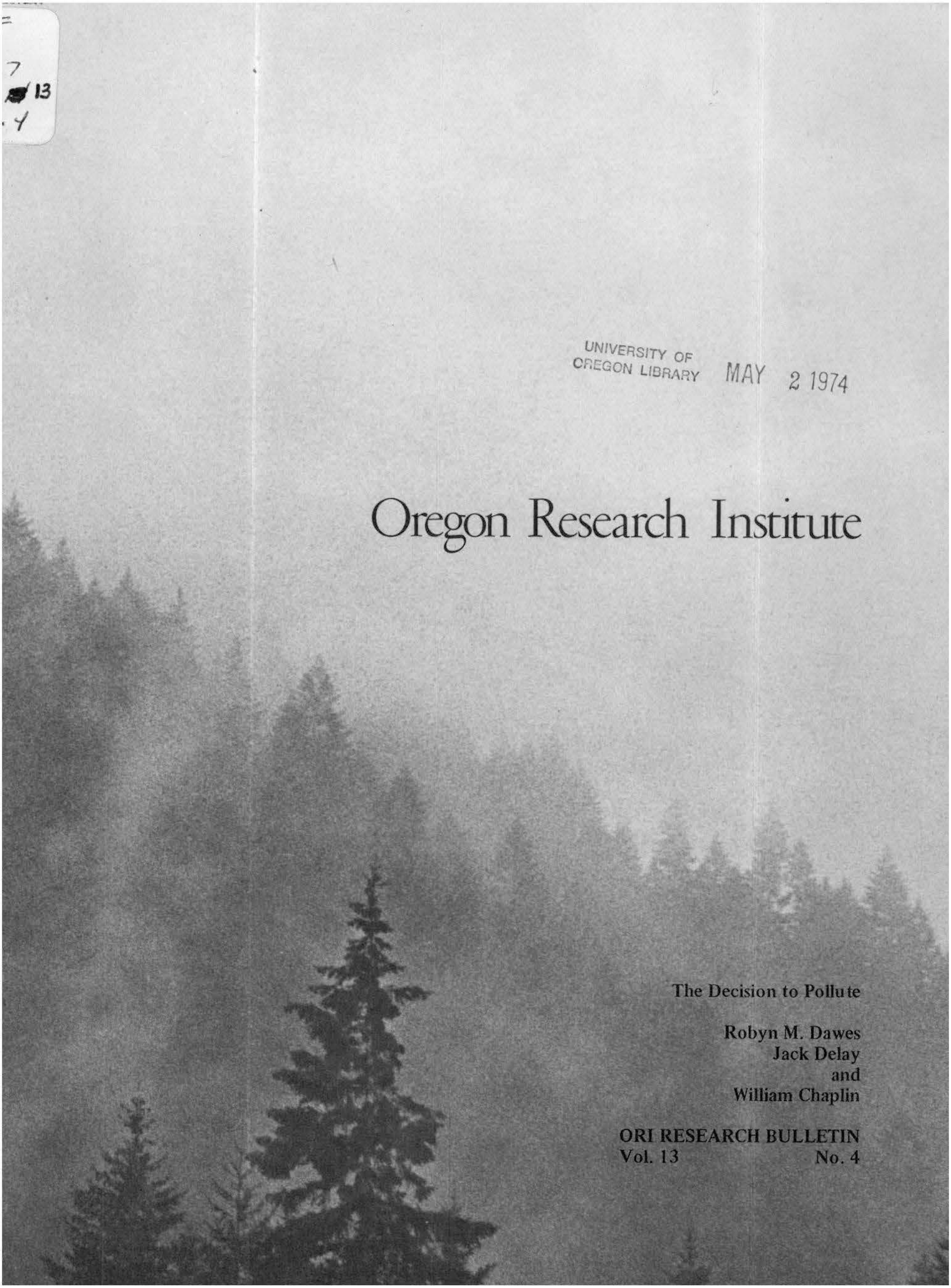

Oregon Research Institute

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Abstract

One way of studying the pollution problem is to examine the decision making process in situations in which gain accrues directly to an individual while loss is spread out across the group of which the individual is a member. Such a situation has been termed a commons dilemma by Lloyd in 1833; it is a variant of the well known prisoner's dilemma. The mathematical model of rational decision making when facing the commons dilemma implies the dismal conclusion that individuals acting rationally will end up destroying, or nearly destroying, the common wealth. Suggestions are made concerning ways in which people may be persuaded not to pollute our environment.

THE DECISION TO POLLUTE[1,2]

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The decision to pollute our environment has been discussed recently by Garrett Hardin in an article entitled "The tragedy of the commons."[3] He investigated this problem by looking at the hypothetical situation described previously by the amateur mathematician, William Foster Lloyd[4], in which a number of people each own 10 sheep grazing on a common pasture. When an individual contemplates obtaining an 11th sheep and letting it graze on the commons, he sees that the gain resulting from such an action accrues to him in the form of increased wealth, while the loss resulting from reduced food supply per sheep is spread out among all the people whose sheep graze on the commons; hence, it is "rational" for him to introduce an additional sheep into the commons; a dilemma occurs because rationality dictates the same conclusion to everyone, and the commons thereby becomes rapidly destroyed.

This same situation occurs in many real-life circumstances, not the least important of which is the decision to reproduce. With the world as our commons, each of us may believe he stands to gain (fulfillment, "eternal life," companionship, and perhaps wealth) by having children, while the loss of adding each additional "consumatory and polluting agent" to the commons is clearly distributed among all the living creatures in it, and particularly the other people. That this one type of pollution may underlie most other pollution problems makes the study and resolution of the class of such problems particularly timely.

The commons dilemma may be regarded as a generalization of the prisoner's dilemma. In this dilemma, two prisoners are being questioned for a crime in which they are alleged to have collaborated. The interrogater (being convinced, as usual, of the guilt of the suspects) offers the following deal to each of them:

> "If you confess and your partner does not you will get off and he will get 10 years. If he confesses and you do not, the opposite will happen. If neither of you confesses, we'll get you both for a year on a reduced charge, but if both of you confess you'll both get five years, so why don't you confess?!"

At first glance it appears that neither suspect should talk. But a closer inspection of the alternatives indicates that the "rational" thing for each suspect to do is to squeal. Consider the situation from the point of view of the first suspect. If the second suspect talks, then the first suspect should also talk, for he will then receive five years in prison instead of ten. On the other hand, if the second suspect does not talk, then the first suspect should still talk, because then he will spend no time in jail instead of one year. Thus, no matter what the second suspect does, the first suspect is better off talking--and the same analysis holds true for the second suspect. It is therefore rational for both suspects to talk. Of course, as a unit the two suspects clearly gain most (lose least) by not talking. But it is precisely the tendency for people not to act in unison that produces both the prisoner's and the commons dilemma. The fact that the prisoner's dilemma paradigm is drawn from an underworld example does not hide the fact that the man who decides to burn his garbage rather than haul it to a dump is faced with the same dilemma . . . and decides to give most of the loss to his neighbors.

More generally, it seems that all decisions about whether to aim for optimal solutions for the individual (small unit size) or for the commons (large unit size) are related to the foregoing dilemmas. There has been a great deal of previous theoretical work in which the structure of the prisoner's dilemma has been examined in detail[5] as well as empirical investigation of how people respond when asked to play the prisoner's dilemma.[6] In the present paper, we will examine the commons dilemma in some detail; this examination will be addressed primarily to the question of under what conditions (or whether) people will stop polluting if they behave rationally.

Following the "sheep commons" paradigm, let K_i be the number of potentially polluting units (e.g., sheep) owned by individual i. Let N $(= \sum_i K_i)$ be the total number of such units. Further assume that the addition of a sheep to the common pasture devalues the worth of each unit by a constant proportion, p, of the original commons. Thus, an individual's worth after N sheep have been introduced is given by

$$W_i = K_i(1 - Np) \quad . \tag{1}$$

Clearly, any monotone decreasing function of N is as reasonable as any other in place of $1 - Np$, but this latter is chosen for simplicity.

At the moment when individual i has a choice of whether or not to pollute the commons further, his wealth if he does so is $(K_i + 1)(1 - (N + 1)p)$, while his wealth if he does not remains at $K_i(1 - Np)$.

His gain, G_i, for introducing another unit is then given by the difference between those two numbers, i.e.,

$$G_i = (K_i + 1)(1 - (N + 1)p) - K_i(1 - Np), \quad (2)$$

which simplifies to $1 - (1 + K_i + N)p$. Under the assumption that any positive value for G_i induces the rational individual to pollute, we can conclude that individual i will pollute or not depending on whether $K_i + 1$ is less than or greater than $\frac{1}{p} - N$.

Note that for $N < \frac{1}{p}$, this expression will always be positive. Hence, an individual with no wealth will always add a polluting unit. But when N finally reaches the value $\frac{1}{p}$, the entire commons is destroyed! Thus, the specific commons dilemma model proposed here implies that individuals with no wealth whatsoever will pollute so long as there is any wealth left.

The deterioriation of the commons is given by $1 - Np$. The total worth of the community raising N sheep, W(N), is equal to the sum of the individual wealths.

$$\begin{aligned} W(N) &= \sum_{i=1}^{M} W_i \quad (3) \\ &= \sum_{i=1}^{M} K_i(1 - Np) \\ &= N(1 - Np). \end{aligned}$$

The maximum value for W(N) is given by taking the first derivative of this value with respect to N and setting it equal to 0.

$$\frac{dW(N)}{dN} = 1 - 2Np = 0 \quad (4)$$

$$N = \frac{1}{2p}$$

At that point $W(N) = \frac{1}{2p}(1 - \frac{p}{2p}) = \frac{1}{4p}$.

Now, consider that there are M individuals and that they all have equal wealth. In that situation, each K_i will equal $\frac{N}{M}$, and people will stop polluting when $\frac{N}{M} + 1$ becomes greater than $\frac{1}{p} - N$. Solving for N, we observe that people will stop polluting whenever

$$N > \frac{(1 - p)}{p} \cdot \frac{M}{(M + 1)} . \qquad (5)$$

Note that for p small and M large, the right-hand side of the inequality will approach $\frac{1}{p}$, the point at which the commons is completely destroyed. Note further, that only for M = 1 and p small will this expression approximate $\frac{1}{2p}$, the point of maximum wealth. In other words, the model presented predicts that only in the case of a single individual (or in the case of everyone behaving as if they constitute a single individual) will maximum wealth be obtained from the commons, and then as more and more individuals behave rationally, the commons will be more and more destroyed before people stop polluting--the limiting case being that if there are an indefinitely large number of people capable of polluting the commons, it will be destroyed entirely. Table 1 presents what happens at various values of M for p's of .01, .005, and .001. Table 1 also includes the maximal potential wealth per individual (at the point at which the collective wealth is maximized) and the actual amount of wealth per individual (at the point at which the individuals stop polluting). In addition, Table 1 presents 1 - Np at the point individuals stop polluting, which is extremely well approximated by $\frac{1}{M + 1}$. (The algebra of this approximation is omitted here; it involves substituting the right-hand part of Equation (5) for N and noting that p is very small.) Thus, as

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Insert Table 1 about here

TABLE 1

Results of Equal Wealth

1a. p = .01

M	N at time pollution stops	W(N)	1 - Np	maximum W/M	actual W/M
2	67	22.11	.33	12.50	11.05
3	75	18.75	.25	8.33	6.25
6	86	12.04	.14	4.17	2.01
10	91	8.19	.09	2.50	.82
50	98	1.96	.02	.50	.04

1b. p = .005

M	N at time pollution stops	W(N)	1 - Np	maximum W/M	actual W/M
2	134	44.22	.33	25.00	22.11
3	150	37.50	.25	16.67	12.50
6	172	24.08	.14	8.33	4.01
10	182	16.38	.09	5.00	1.64
50	196	3.92	.02	1.00	.08
100	199	1.00	.01	.50	.01

1c. p = .001

M	N at time pollution stops	W(N)	1 - Np	maximum W/M	actual W/M
2	666	222.44	.33	125.00	111.22
3	750	187.50	.25	83.33	62.50
6	857	122.55	.14	41.66	20.43
10	909	82.72	.09	25.00	8.27
50	980	19.60	.02	5.00	.39
100	990	9.90	.01	2.50	.10

illustrated in the table, the actual amount of wealth per individual when pollution stops is less than half the maximal amount when there are as few as six individuals--and the situation rapidly deteriorates when there are more.

Whenever there is an unequal distribution of wealth, the model predicts that there will be even more pollution. For while individual i decides whether or not to pollute on the basis of the value of K_i, the decision about whether or not there is to be <u>any</u> pollution is based on the minimal K_i. It is only when this minimal $K_i + 1$ is greater than $\frac{1}{p} - N$ that pollution ceases entirely. But for a given N, the minimal K_i will be largest whenever all K_i are equal. Hence, the values given in Table 1 are upper bounds for community and individual wealth.

Observing that in the real world an individual's ability to pollute (by an extra sheep) is typically related to how wealthy he already is, we designed a computer simulation of the model in which the probability that an individual had a chance to pollute was proportional to his wealth at the time. We began the simulation at Step 1 with each individual's having one sheep. At Step 2, one of the individuals was chosen at random and allowed to add an extra sheep. At each subsequent step a single individual was chosen and allowed to add a sheep; the probability that the individual chosen would be the ith was equal to K_i/N.

Since wealth is not equally distributed by this process, the outcomes are again worse than the outcomes presented in Table 1. Of more interest, however, is the process by which the outcomes are reached. What happens is that one or two individuals get far ahead of the others in wealth very quickly and they stop polluting, since it is no longer profitable for them. However, it still remains profitable for the "poor" individuals to pollute and they do so . . . until the commons is either destroyed or very nearly so. It is also interesting that the "rich" decide to stop much closer to the point of maximum wealth for the community than do individuals in the equal wealth situation. If nations may be regarded as individuals deciding whether or not to pollute according to our model, then our simulation indicates that the wealthy nations will stop polluting much sooner than will the poorer, or developing, nations. We note that in recent years it has been precisely the wealthier nations that are most concerned about the pollution problem, while some of the developing nations not only evidence lack of concern, but are actively opposed to world efforts to stop pollution--on the grounds that such efforts would stifle their development.[7]

One problem with the existing model is that it does not account for the possible effect of individuals who refuse to pollute. Adding such individuals to the commons leaves the results unchanged.[8] For the only factors which determine the gain for an individual are the pollution factor, the total number of sheep, and the number of sheep owned by that individual. In the real world, however, members of the community who either refuse to pollute or have no access to the means of pollution do have an effect.[9] Farmers sue aluminum companies, conservation groups lobby for legislation, and individual members vote for politicians who promise to stop pollution. Another problem with the model as stated is that a pollution factor often does not feed directly back upon the unit creating the pollution. While overcrowding of sheep on a commons may lead to less grass per animal, a more typical situation is one in which a pollution caused by one unit or process has negative effects on another--e.g., waste from a factory does not harm the factory, but rather kills fish.

The model can be modified accordingly. In place of a pollution factor, we introduce a "reaction factor," R. This factor is assumed to be a monotonically increasing function of the pollution factor, p. For simplicity, we assume a direct linear function

$$R = Vp \quad (V \geq 0) \tag{6}$$

Thus, if there is no pollution (p = 0), there is also no reaction (R = 0), and whatever the value of V, larger pollution factors evoke larger reaction. This new term, V, may be regarded as the "visibility" of the pollutant. In the real world, visibility has both physical and psychological components. The visibility of a pollutant can be great as a result of either its noxious nature or a well-managed publicity campaign.[10] In the model, large values of V may be associated with what has been characterized as "over-reaction" to ecological problems, while small values of V are associated with what many believe to be dramatic underestimation of the pollution problems.

For V = 1, the model makes the same predictions as the previous one. If V is less than 1, the situation becomes even worse. That is, if the pollution has low visibility, then its effects upon the decision to increase production will be less than that which occurred if the pollution had fed back directly upon the means of production. But in the latter case, any model predicts destruction of the environment well past the point of maximum wealth, and almost total destruction as the number of individuals (or polluting agents) becomes large.

Values of V greater than 1, however, lead to much more satisfactory results. When the value of V is 2, for example, the individuals will stop polluting at the point at which maximal community wealth is reached. Larger values of V will lead to an end to pollution prior to the time the maximal community wealth is reached, but the community as a whole (hence, all the individuals in it) is much better off stopping too soon than stopping too late.

Another way in which the model may be modified is to introduce a "tax" or cost for polluting. The effect will, of course, depend upon the amount of this tax. There is, however, one general result that may be of some interest--because it points up one severe problem with the taxing scheme.

Suppose that a tax is devised to maximize community wealth. That is, a tax, t, is assessed in such a way that

$$(K_i + 1)(1 - (N + 1)R) - K_i(1 - NR) - t = 0 \tag{7}$$

at the point of maximum community wealth, i.e., at $N = \frac{1}{2p}$. Solving for t we obtain

$$t = (\frac{2p - R}{2p} - R) - RK_i \tag{8}$$

that is, t must be an inverse linear function of K_i. The poorer the individual, the more tax he must be assessed. This result is not at all paradoxical, because it is the more wealthy individuals who suffer most from the pollution, and hence they need not be assessed as much of a tax as must the poorer individuals if pollution is to be discouraged. (Again, see Footnote 7.) Olsen[11] has reached a similar conclusion with regard to the formation of labor unions; it is often those who are best off who are motivated to make the personal sacrifice involved in forming or joining a union--because they have the most to gain. In the current context, it is they who have the most to lose by continued pollution.

There are other ways in which the basic model presented here might be extended. For example, we might consider: (i) continuous, rather than discreet, polluting behavior, (ii) the fact that many commons replenish themselves over time, (iii) a more sophisticated concept of utility rather than wealth, (iv) the possibilities of coalitions among the members[12], and (v) a wider variety of functions relating pollution decisions to variations in total wealth. While we have experimented with several of these variations, none has led to conclusions substantially different from those presented above.

Discussion

If the "proper" value for V is regarded as 1 (i.e., the reaction to the pollution is exactly equal to the amount of harm done by it), then veridical perception ends up with the commons destroyed--or nearly so. On the other hand, people are better off overestimating, or "over-reacting," to the pollution factor--and far better off overestimating than underestimating.

But will people overestimate? There has been a great deal of psychological work showing that people will respond not to the absolute values of sensory stimuli but to their values in comparison to stimuli with which they are familiar--i.e., to their adaptation-level.[13] Thus, a light weight is judged (perceived to be?) lighter the heavier the context of weights in which it appears. Extrapolating, we would predict that a perception of--or at least a judgment of--a given amount of pollution will judged to be greater the less polluted the context in which it appears. But pollution is an insidious process, in which each tiny deterioration of the environment may be accepted as the context in evaluating further deterioration; hence, adaptation-level theory predicts that it would tend to be underestimated rather than overestimated.

Much the same conclusion has been reached by Reichardt[14] who writes that "human beings are adapting to environmental conditions, also to very unsatisfactory ones from the point of view of possible choices. Therefore, we cannot expect too much information from surveys on housing quality, etc., as people have little experience with other possible environments and therefore cannot objectively compare their own condition to which they are accustomed with the others."

The adaptation factor, at least in the United States, may be further complicated by the high mobility of labor. Many people move to new environments every three to four years. Even though this move may bring a sudden contrast in the amount of pollution, and hence appreciation of the pollution or lack thereof, the perceived difference is easily explained in terms of the actual physical location--rather than in terms of a temporal process. For example, the person who moves to Los Angeles is prone to believe that "This is Los Angeles," rather than that "Los Angeles is getting worse." What we might observe as transient citizens of subtle but ongoing deterioration certainly cannot be great compared to what a 50-year time lapse film of one neighborhood might reveal.

To recapitulate. Our model indicates that underestimating pollution involves much greater risk than does overestimating it. Yet basic mechanisms of human perception and adaptation tend to make underestimation much more likely (people who have an accurate perception, therefore, may be widely regarded as exaggerating the problem--i.e., as "eco-nuts").

That population and pollution are already the most pressing problems of our times is a well-argued case.[15] Progress is being made in the more industrially advanced nations toward the goals of a stabilized population.

But as Heilbroner so eloquently argued, the analogous notion of "zero industrial growth" that is entertained in some circles cannot provide an analogous solution.[16] Even under the most optimistic assumptions of population growth there will be extreme increases in the demand for production of food, textiles, energy, and shelter over the next century.

Further, our model predicts that the individuals with the smallest amount of wealth are those that have the largest economic motive to pollute. If the generalization may be made to nations, we predict that there may be a dramatic increase in industrialization in the less advantaged nations without comparable concern for pollution.

We do not yet have any hard empirical evidence that our model is correct--i.e., that people will behave in a manner dictated by the structure of the commons dilemma. We are concerned, however, that supporting evidence will be forthcoming, and soon.

Escaping the Dilemma

No discussion of polluting behavior would be complete without something said about how to escape the apparent dilemma. We think that our model has at least pointed in one direction that escape might take.

First, it cannot be overemphasized that a single rational polluting agent, given a decent estimate of the pollution, always stops polluting when his (and thus the community's) wealth has been maximized. Thus, any community that acts as though it were a unit has solved the problem. But we all knew that.

The smaller the number of polluting agents, the better. And the less the maldistribution of wealth, the less the destruction--although it must be emphasized that the destruction comes from the individuals who lack wealth, not from those who have it.

Suppose, to return to the original concrete example, each of 10 individuals has a 100-lb. sheep. If one then adds an additional sheep to the pasture, each of the sheep decreases in weight to 90 pounds; thus, that individual has increased his wealth by 80 pounds of sheep. However, suppose that these 10 individuals form into two groups of five and one of the groups decides to add an additional sheep. Instead of having five 100-lb. sheep, the members of that group would now have six 90-lb. sheep, so that the increase in total wealth is only 40 pounds. Each individual in the polluting group thus gains only 8 pounds, a decrease of a factor of 10 over the ungrouped example. It is clear that the motive to pollute is much lower for each individual of the group than it is for an individual acting alone. (Note that just concentrating the <u>wealth</u> in a small number of units not only does not solve the problem, but exascerbates it, granted that the poor are as rational in their pursuit of individual gain as are the rich.) Therefore, even larger coalitions of polluting units can be suggested (farm co-ops, industrial planning bureaus, super-national units) to help solve the problem.

References and Footnotes

[1]This article is based on a paper presented on May 2, 1969 at the annual meeting of the Oregon Psychological Association; it was supported by Grant MH-12972 from the National Institute of Mental Health, U.S. Public Health Service. At the time it was written, Mr. Chaplin was an employee of the Oregon Research Institute (ORI). We would like to thank our ORI colleagues, in particular Dean Peabody, for helpful editorial comments.

[2]By 'pollution' we mean any exploitation of the environment that results in an overall decrement in the amount of real or potential wealth that can be extracted from it. For example, harvesting whales at a rate that results in a decrease of the population is considered pollution, while harvesting at or below the level of "maximal sustainable yield" is not.

[3]Hardin, G. The tragedy of the commons. Science, 1968, 162, 1243-1248. See also Exploring new ethics for survival: The voyage of the Spaceship Beagle. Baltimore, Md.: The Viking Press, 1972.

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[7]Bazell, R. J. Human Environment Conference: The rush for influence. Science, 1971, 174, 390-391. ["In speaking before a U.N. committee on 8 October, the ambassador to the United Nations from Brazil, Sergio Armando Frazao, declared that he saw in some aspects of the concern for the environment in wealthy countries a 'malicious trend according to which the old patterns of colonial paternalism are being replaced by a pseudo-scientific outlook to justify nondevelopment.'"]

[8]This is not the case only when enough members (with one sheep each) are added to start the simulation at a point beyond the limit for all members.

[9]As we are dealing with production that creates by-product pollutants, the terms "means of production" and "means of pollution" are interchangeable.

[10]Visibility could be viewed as more general and include, for instance, the altruism of management in a particular industry.

[11]Olson, M. The logic of collective action. Cambridge, Mass.: Harvard University Press, 1965.

[12]See Shapely, L. S., & Shubik, M. On the core of an economic system with externalities. American Economics Review, 1969, 59, 678-684.

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[14]Reichardt, R. Dilemmas of economic behaviour vis-a-vis environmental pollution. Kyklos, 1970, 23, 849-865.

[15]See A blueprint for survival. The Ecologist, 1972, 2(1), 1-43 (entire issue). Also Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W. The limits to growth. New York: Universe Books, 1972.

[16]Heilbroner, R. L. Growth and survival. Foreign Affairs, 1972, 51, 139-153.