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THE CAUSES AND CONSEQUENCES OF THE COMMONS DILEMMA IN NATURAL RESOURCE ECONOMICS

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The "commons dilemma" emerges in the natural resources literature as a central metaphor for the pitfalls of joint decisionmaking. Its centrality derives from the wide variety of cases in which external effects result from interdependent choices over the use of natural resource stocks and flows. Because of the universality of these problems, any framework that can supply insight into their nature is useful. Yet the structural simplicity of the "commons dilemma" as it is usually portrayed, notably by reference to the "Tragedy of the Commons" (Hardin, 1968) or more formally as an n-person Prisoners' Dilemma game, obscures important and complex issues with which economic theory is increasingly concerned. These include strategic choices characterized by the absence of dominant strategies and unique equilibrium outcomes; the treatment of external effects in relation to "missing markets"; and the role of information in coordinating choices where the central analytical and empirical issue is expectations formation.

This paper has three basic purposes. The first is to review a rigorous framework for the analysis of commons dilemmas proposed by Dasgupta that avoids many basic faults of the usual apparatus. The second is to relate this analysis of the commons to models of external effects and public goods. Properly formulated, the commons dilemma may be considered as a choice constrained by these

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external effects, making it a problem of the "Second Best." The third purpose is to extend the analysis into the literature on strategic interdependence, especially problems in the economics of expectations formation. The paper concludes with a general summary of the redirections implied for both theory and empirical research in natural resource economics.

I. Modeling the Commons

The "commons dilemma" arises from the simple observation that resources managed jointly are often used nonoptimally from the point of view of society as a whole, even though choices respecting their use appear individually optimal. In the literature on overgrazing, overforesting, overpopulation, overdrilling for oil or water, and even overspending the budget, this dilemma can be described as one of incompatibility between individual and collective incentives. This "incentive incompatibility" (see Hurwicz, 1972) results in nonPareto-optimal outcomes. Perhaps the most vivid description of this problem in the modern literature[1/] is Garret Hardin's widely cited article, "The Tragedy of the Commons" (1968). Hardin writes:

> Picture a pasture open to all. It is to be expected that each herdsman will try to keep as many cattle as possible on the commons ... As a rational being, each herdsman seeks to maximize his gain. Explicitly or implicitly, more or less consciously, he asks, 'What is the utility to me of adding one more animal to my herd?' ... Adding together the component partial utilities, the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another; and another ... But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. 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 the commons brings ruin to all (p. 1244).

Partha Dasgupta has recently observed that "It would be difficult to locate another passage of comparable length and fame containing as many errors as the one above" (1982, p. 13). These errors are partly omissions. As Dasgupta notes, although commonly used resources may well be overexploited, it is not because adding more cattle to the herd is costless, even to the individual herder. Nor can we know how costly such actions will be, either to the individual or to society, without additional information. In fact, freedom in the commons may not bring ruin to all. It may ruin some -- or none. These are issues that bear closely on the provision of collective goods, the size of the group making the collective consumption choice, and their selective incentives to do so (Olson, 1965).

There are also more serious analytical difficulties with Hardin's analysis. These errors of commission are best seen in the argued equivalence between "tragedy" and the almost equally well-known Prisoners' Dilemma game, widely used to describe the problem of collective consumption choices and the incentive to free ride. The difficulties with this approach (see Runge, 1981; 1982; 1984a) have led to a search for more complex and realistic models, notably an iterated or repeated Prisoners' Dilemma, in which dominant strategies to free ride break down, and "tragedy" may be avoided through voluntary cooperation (Barry, 1965; Taylor, 1976; Hardin, 1982; Axelrod and Hamilton, 1981).

Because this discussion is widely familiar, it need not be repeated in detail, except to note that even in its iterated form, the Prisoners' Dilemma "is not rich enough to capture a useful abstraction of human affairs" (Shubik, 1970, p. 190). The essence of the single-period Prisoners' Dilemma is that in each period, a unique non-cooperative, Pareto-inferior (Nash) equilibrium is sustained by dominant free rider strategies. Dominant strategies make expectations of others' actions irrelevant, obviating the necessity of forming expectations or gaining information about these actions. Yet it is precisely the interdependence and jointness of the commons that make expectations of others' behavior so crucial to a resolution of the problem. In its iterated form, it is the question of expectations over time that makes the repeated Prisoners' Dilemma a more plausible model than the single period game.

What is implied by Hardin's classic article and mistakenly described by the Prisoners' Dilemma (although partially corrected in its iterated form) is that each of the agents using a common pool resource could benefit if they jointly were to exercise some control over the common (Dasgupta, 1982, p. 14). This joint control must be based on cooperative contingent strategies, which in turn depend on correctly predicting and evaluating the likely strategies of others (Runge, 1984a). The key issues, therefore, are how such joint decisions are informed, what factors constrain them, and how they are enforced. In order to clarify these issues, a model is required that recognizes the joint nature of common resource decisions, as well as the role of expectations arising from the interdependence of individual choice.

Consider a case of N identical users of a common property resource, in which each agent, in the course of production, imposes a negative external effect in the form of damages on the others sharing the common.[2/] Assume that the only way to reduce this negative external effect is to reduce production output (e.g., by "stinting" on cattle grazed, reducing fishing or foresting effort, drilling fewer wells, etc.). Intertemporal elements may be introduced into the model (e.g., Dasgupta, 1982, pp. 150-177). Here, however, we assume no distinctions between stocks and flows. Let y_i denote the output of agent i, where $i = 1, \ldots, N$ and let z_i denote the negative external effect, where

$z_i = \alpha y_i$. If we measure this external effect in such a way that $\alpha = 1$, we can simply identify z_i and y_i. In addition, assume that the share of collective benefits, not including external effects, that agent i enjoys when it produces y_i is given by the function $B(y_i)$. This includes the cost of producing y_i, so that we can describe this benefits function as rising with increases in y_i up to a point, then falling as the costs of production increase, as in Figure 1 below. Eventually these costs lead to negative benefits.

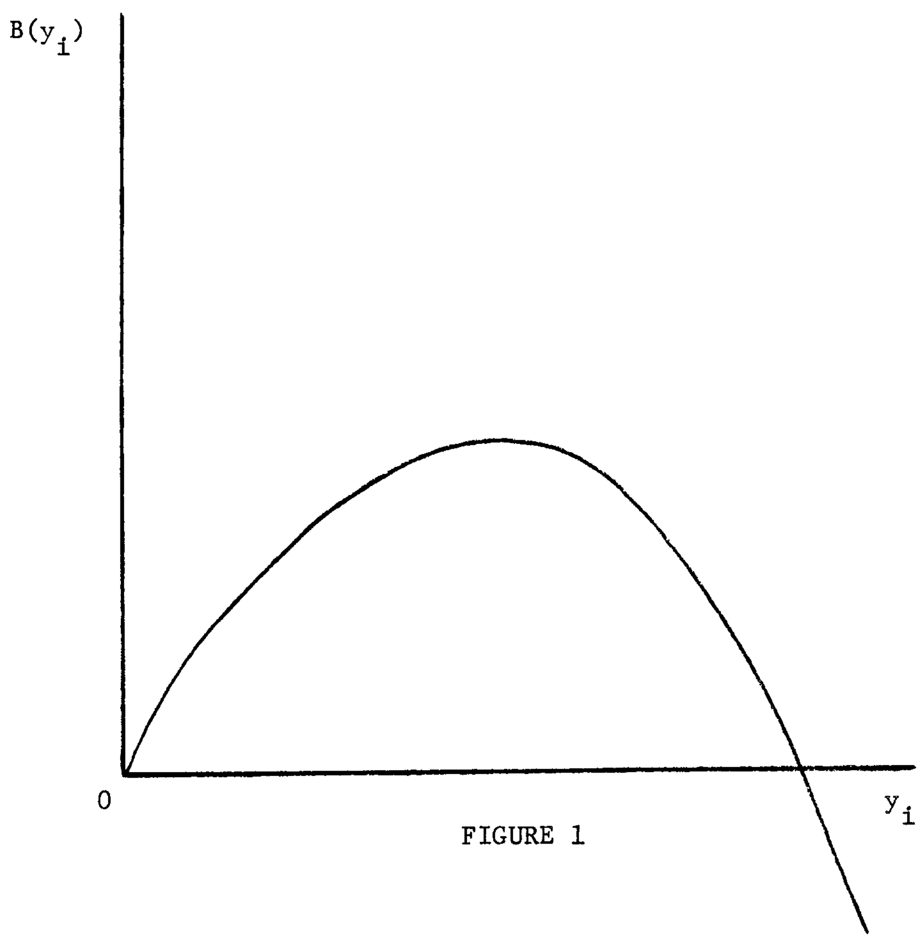

FIGURE 1

The negative externality also leads to reductions in total output. This loss can be described for each agent by the damage function

$$D\left(\sum_{i=1}^{N} z_i\right) = D\left(\sum_{i=1}^{N} y_i\right)$$

where $\sum_{i=1}^{N} y_i$ is total output and the identity defined for z_i and y_i above holds. This damage is a positive function of total output, as in Figure 2.

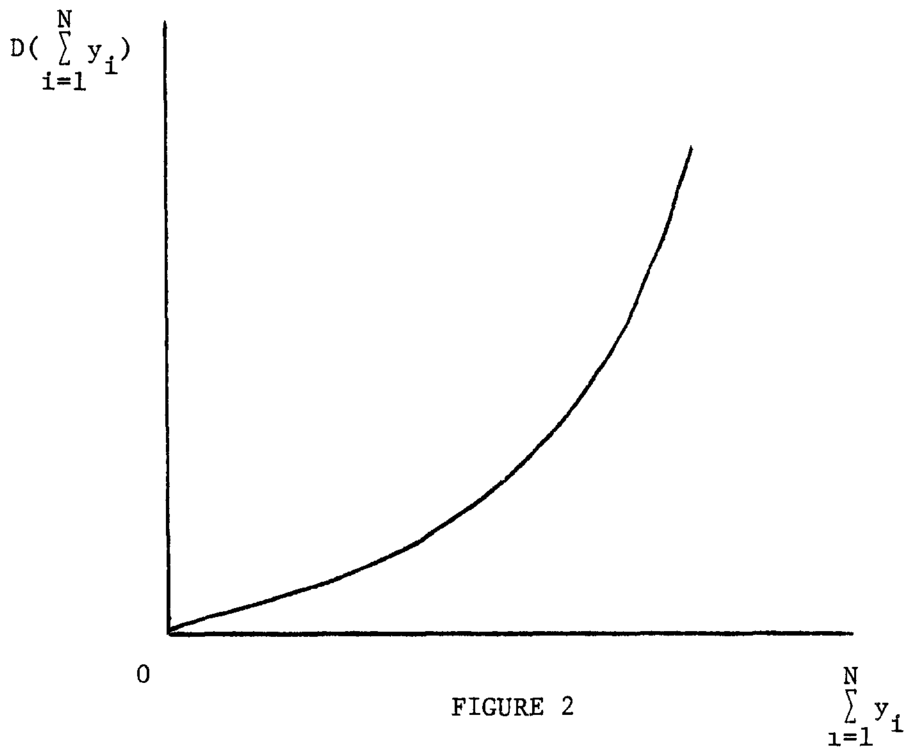

FIGURE 2

With this apparatus, we may define the non-cooperative outcome loosely referred to in the literature as a "tragedy." A given agent i, assuming that each of the other agents will produce a given amount, say y, concludes that net social benefits (including losses from external effects) would be

(1) $$B(y_i) - D(y_i + (N - 1)y).$$

Since agent i can only choose y_i, he takes y as given, and maximizes his own net benefit. Maximizing (1) by taking first order conditions yields agent i's "individualistic benefit cost rule."

$$(2) \quad \frac{\partial B(y_i)}{\partial y_i} = \frac{\partial [D(y_i + (N - 1)y]}{\partial y_i}$$

Since the agents are assumed identical, if y_i is individually optimal for agent i it is also optimal for the other (N - 1) agents and defines an equilibrium in which $y_i = y$. Equation (2) can, therefore, be expressed equivalently as

$$(3) \quad \frac{\partial B(y)}{\partial y} = \frac{\partial D(Y)}{\partial Y}$$

where Y = Ny. A unique non-cooperative (Nash) equilibrium value exists for the unknown quantity y which we may call $\bar{y}$. Total output is thus $N\bar{y}$ at this equilibrium, where each agent equates marginal benefits from production with marginal costs due to the negative external effects of this production.

The "tragedy" is that following the individualistically optimal benefit cost rule is collectively nonoptimal. This is shown by the fact that the sum of individual benefits is not maximized by following the rule given by (3). Rather, the collective maximum is given by

$$(4) \quad NB(y) - ND(Ny)$$

Taking first order conditions with respect to y where Y = Ny, yields a "collective benefit-cost rule."

(5) $\frac{\partial B(y)}{\partial y} = \frac{N \partial D(Y)}{\partial Y}$

This expression equates the marginal benefits to a representative agent from increases in output with the sum of marginal damages to each agent. It is simply a form (for public "bads") of the expression for the optimal supply of public goods (Samuelson, 1954). If y* is the solution to (5), then inspection of (3) indicates that $\bar{y} > y^*$. The incentives described by the individualistic benefit cost rule yielding $\bar{y}$ are thus incompatible with those described by the collective benefit cost rule. In the absence of a joint strategy in which output is reduced each agent will produce too much despite the fact that all agents are collectively better off producing at level y*. This result is shown graphically in Figure 3.

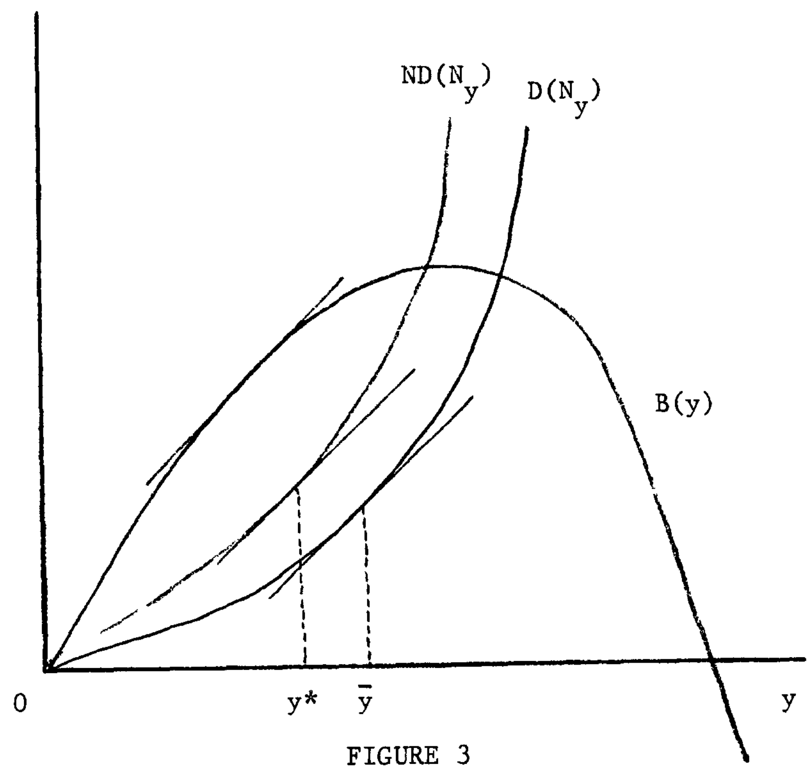

FIGURE 3

It must be emphasized that this outcome is not formally equivalent to the Prisoners' Dilemma, principally because it is not characterized by dominant strategies for each agent (Dasgupta, pp. 23-24). As noted elsewhere (Runge, 1981), the Prisoners' Dilemma game leads not only to a unique non-cooperative Nash outcome that is Pareto inefficient, but also depends on the dominance of free rider strategies to sustain this equilibrium. In equation (3), by contrast, $\bar{y}$ is the best strategy for an individual agent <u>if and only if</u> the remaining agents produce negative external effects equal to $(N - 1)\bar{y}$. Hence, the decision of each agent is contingent on the expectation that other agents will act in a particular way. In the Prisoners' Dilemma, by contrast, expectations are simply irrelevant; it is always optimal to produce too much and free ride no matter what others do. If an agreement can be reached in which each agent expects others to produce at level y^*, there is no reason to suppose that overproduction will occur. Such an agreement, however, requires the assurance that agents' ex ante expectations of the actions of others will be realized, ex post. With this assurance, "tragedy" is not inevitable, and is, in fact, entirely avoidable.

This result is broadly consistent with the findings of Cornes and Sandler (1983), who have argued on theoretical grounds that Nash behavior is an inappropriate basis for modeling common property (see also Runge, 1984a). Depending on whether agents expect that others will either overexploit or underexploit a common property resource in reaction to ones' own behavior, the commons may be more or less "tragic" than the Nash equilibrium described above. Cornes and Sandler argue, however, that in the absence of fixed costs and barriers to entry, additional firms (even two) will be led to overexploitation. It is precisely the role of institutional agreements to fix these costs, impose barriers to entry, and establish "expectations contours" for the agents sharing the commons. With such agreements, overexploitation is not inevitable.

Hence, "tragedy" is avoidable in cases of common property externalities, so long as agreements can be structured that coordinate the expectations of individual agents according to a rule that takes account of collective welfare. Before exploring the properties of such rules, it is useful to consider in more detail the links from the analysis above to the literature on public goods and problems of the "Second Best."

II. The Commons, Public Goods, and External Constraints

The relationship between common property and the more general issues of public goods and externalities is often mentioned, yet not rigorously explored. It was noted above that the asymmetry in commons dilemmas between individual and collective decisions takes the form of the classical distinction between private and public choices first developed by Samuelson (1954). The individualistic benefit cost rule differs from the collective benefit cost rule because the collective rule is derived from maximization of the vertical sum of benefits for all agents, whereas the individualistic rule is derived from maximization of the horizontal sum. This distinction arose in the context of externalities, emphasizing the close similarity between commons dilemmas, public goods and external effects. Demonstrating this similarity requires further analysis.

The commons dilemma is a case of negative external effects in which these effects fall jointly on members of the group that shares the commons. The negative effects are, therefore, collective bads. These bad effects upset the mechanism that would lead to a Pareto-optimal allocation based on individualistic benefit cost rules, creating the classical divergence between private and social welfare. The external effect or (equivalently) the collective bads borne by users of the commons represent a constraint on the capacity of users to achieve a Pareto-optimal allocation. By constraining the choice of these agents, they alter first-order conditions for optimization, resulting in a problem of the Second Best (Lipsey and Lancaster, 1956-57). So long as the individualistic benefit cost rules contain these effects, the commons dilemma must be addressed as a problem of strategically interdependent choice.

Returning to the model above, let F_1 represent the production function of a given agent in the commons, of the form

(6) $F_1 = (x_1^1, x_1^2, x_1^3, \ldots, x_1^m; y_{i \neq 1})$

where the $x_1^1, x_1^2, x_1^3, \ldots x_1^m$ are m inputs to agent 1's production and $y_{1 \neq 1}$ is the external effect of the production decisions of all other agents on agent 1. Where this effect is negative, we may define it as the cost in foregone output resulting from joint use of the commons. What we need to emphasize is that in the short run, without some agreement regulating or eliminating the term $y_{1 \neq 1}$ from agent i's production function, the external effect must simply be taken as given. It is not a control variable for agent 1. Its presence defines an externality arising from joint use of the commons, in which the effects on total output cannot be excluded by an agent acting individually. We may, therefore, define a particular level of the external effect as a constraint on the production possibilities of agent 1, such that the individual's maximization problem takes the form:

$$\pi_1(p, w; y_{1 \neq 1}) \equiv \underset{x}{\text{Max}}\ p \cdot F_1(x_1; y_{i \neq 1}) - w \cdot x_1$$

where π_1 is the first individual's profit, p is a vector of output prices, w is a vector of input prices, and x_1 a vector of agent 1's inputs. The existence of the external effect alters the marginal conditions for optimization and is a distortion or "deviation" leading to a Second Best problem. Typically, the analysis of common property assumes that the marginal conditions for optimization are negatively affected by the existence of the externality, and that output moves _away_ from Pareto-optimality. However, there is no basis in theory for arguing that this is always so. Indeed, empirical evidence suggests numerous examples in which common property may not lead to Pareto-relevant constraints on production (see Runge, 1984b). Moreover, the General Theory of the Second Best implies that solutions to the optimization problem above will generally be different from those that solve the problem in the absence of external effects, e.g. as under a fully privatized arrangement. In other words, optimization results derived from the case in which Pareto-relevant external effects are absent by definition due to full privatization are _not_ appropriate in the commons, if joint use is unavoidable and Pareto-relevant externalities are present (Lipsey and Lancaster, 1956-57). This point has wide-ranging policy relevance, since it implies that common property arrangements require a different set of information for optimal decisions than private property arrangements. As Bromley notes, if the institutional structure changes then the ability even to compare one set of institutions with another according to the Pareto criterion is threatened (Bromley, 1982).

Suppose that the externality is relevant and negatively affects individual's optimization problem, so that

$$(7) \quad \frac{\partial \pi_1}{\partial y_{i \neq 1}} \equiv \lambda_1 < 0$$

The consequence is that agent 1 is motivated as a result of the negative external effect to make some effort to modify the actions of the other (N-1) agents by alleviating the current constraint on production. In the short run, the value to agent 1 of making this effort is simply agent 1's shadow price for the external effect, or λ_1. This shadow value describes the "payoff" to changes leading to reductions in the negative external effect. This payoff is, of course, not a market price. Indeed, the fact that the effect giving rise to this payoff is external suggests that such a market is missing. Nonetheless, the relative size of this payoff is a direct and increasing function of the negative effect resulting from the collective "bads" borne as a consequence of the current institutional or technological arrangement. The higher is λ_1, the greater the incentive of agent 1 (and, where agents are identical, other agents as well) to innovate rules of resource use leading to reductions in these negative external effects. These innovations may include new property rights arrangements, alternative technologies, or other changes (see Hayami and Ruttan, forthcoming, 1985). It should be observed that optimal solutions in both the short and long run may well involve retention of a structure of joint use.

Here, I have distinguished between the short run, during which the external effect is not a control variable, and the long run, in which the external effect may be mitigated through endogenous technical and/or institutional innovations. In the short run, in other words, technology and property rights are fixed. In the long run, the shadow value associated with the externality, especially where large, creates incentives to innovate both new technology and new property rights. In the case of individual utility functions, an analogous argument can be made concerning the endogeneity of tastes, in which people "learn to live with" the externality and can eventually become indifferent to it (see Von Weizsacker, 1971).

Numerous technological innovations may be direct responses to the constraints imposed by external effects in common pool resources, including, for example, water filtration and sewage treatment devices for individuals utilizing a common water source. In the short run, water pollution constitutes a collective bad that can seriously constrain productive activity. This constraint raises the payoff to innovations such as sewage treatment, eventually making collective action rational to overcome the bad by the installation of a public good.[3/] There are also a wide variety of institutional alternatives that may be innovated in such cases, such as the development of a water authority to regulate use, fine polluting activity, and so forth. Ultimately, judgements over the optimality of these innovations depend on ex ante estimates of the marginal benefits derived from eliminating the external effect (measured by λ_1) compared with the marginal costs of the information, time, or transactions required to do so. The general implication of this analysis is that common property externalities are really constraints imposed by agents on one another, the alleviation of which can occur -- at a (shadow) price. This shadow price is a form of non-market signal indicating the marginal benefits of alleviating the external effect.

This analysis of common property externalities is formally equivalent to the problem of collective bads (goods). The only difference between the external effect and the public bad or good is the number of agents affected (see Mishan, 1971, pp. 11-14). As is well known, for private goods marginal rates of substitution are revealed in the market, and are thus equal to the ratio of prices. In the case of "pure" public bads or goods, in the short run agents cannot adjust levels of consumption or (equivalently) adjust the level of external effects. This lack of flexibility eliminates the price mechanism as a basis for Pareto-optimal allocations of public goods, and also suggests that public goods are simply a special case of the constraint associated with an external effect (Mishan, 1971).

A further observation is that just as negative external effects in the short run may lead to incentives for institutional or technical innovations in the long run, so will the existence of public bads. The more widespread negative effects with high individual shadow values, the more "public" they become, and the greater the collective incentive to alleviate them. In either case, the Second Best nature of the optimization problem implies that market prices are an insufficient signaling device leading to such innovations. A richer information set of the sort contained in the partial derivative λ_1 above is needed, because a market for the external effect itself is missing.

III. Information and Expectations in the Commons

I would now like to turn to the nature of the information set leading to individual choices in the context of common property externalities. If external effects can be understood as resulting from the constraints agents impose on each other, then the theory of the Second Best suggests that non-price information concerning the nature of these effects is required in order to alleviate them. Information concerning the likely actions of other agents will be necessary to determine the solution to the optimization problem arising from joint use itself.

Baumol has argued (1976) that it is impossible to imagine an external effect that is nonseparable in the sense that my optimal reaction to it is independent of your actions and the actions of others in causing it. In order to respond optimally, I need to have formulated an estimate of the effect $y_{i \neq 1} = \bar{y}$ so that I can base my response on this predicted behavior. In the short run, this makes the problem of the commons one of prediction of the likely actions of others, since these actions are not "control variables." In the long run, what were not control variables become so as institutional and technical innovations allow the actions of others to be controlled and therefore made more predictable. This estimation process may be described in terms of an expectations formation problem.

The relationship between the nonseparability of choice, the problem of prediction, and the lack of dominant strategies was first shown by Davis and Whinston (1962). In the context of common property externalities, this relationship is summarized by the statement that wherever external effects are nonseparable, predictions regarding others' actions leading to these effects are necessary data for optimal decisions. In a less general case than the one considered above, suppose two agents in a group use a common property resource. Production functions for each take the general form described above, such that

(8) $F_1 = (x_1^1, x_1^2; y_2)$

(9) $F_2 = (x_2^1, x_2^2; y_1)$

where x^1 and x^2 again are inputs for both agent 1 and agent 2; y_2 represents the external effect of agent 2's production decisions on 1; and y_1 represents the external effect of agent 1's production decisions on 2. These effects are negative, so that

$$\frac{\partial F_1}{\partial y_2} < 0 \text{ and } \frac{\partial F_2}{\partial y_1} < 0$$

In the nonseparable case, the functions take a form such as that below, where A and B are parameters, x_1^1 and x_1^2 are agent 1's inputs of factors x^1 and x^2 and x_2^1 and x_2^2 are agent 2's inputs of the same factors of production. Let

$$F_1 = A_1 x_1^1 - \left[x_1^2 \right]^2 y_2$$

$$F_2 = B_2 x_2^1 - \left[x_2^2 \right]^2 y_1$$

First order conditions for agent 1 and agent 2 are:

<u>Agent 1</u>

$$\frac{\partial F_1}{\partial x_1} = A_1 - 2x_1^2 y_2 = 0$$

Agent 2

$$\frac{\partial F_1}{\partial x_2} = B_2 - 2x_2^2 y_1 = 0$$

The key result is simply that optimal allocations of factors such as x^1 and x^2 cannot be made in the absence of information concerning the output decisions of the other agents utilizing the commons, expressed by y_2 and y_1.

This information may be formally expressed in terms of a probability density function defined for each agent over the likely contributions of others to the collective bad. $E[y_2]$ is the expected (mean) external effect contributed by agent 2, and $E[y_1]$ is the expected (mean) external effect contributed by agent 1. More generally, $E[y_{1\neq 1}]$ is the total external effect expected by agent 1 from all other agents sharing the commons. Surrounding these expectations is some uncertainty, defined as the variance and higher moments of y_2 around $E[y_2]$, the variance and higher moments of y_1 around $E[y_1]$, etc.

Following Stigler (1961), this lack of certainty about the expected external effects of others measures the information each agent holds concerning these actions. The more densely distributed the probability density function of y_2 around $E[y_2]$, the more certainty or assurance each agent has about the likely actions of others, and the more well-defined his nonseparable decision problem becomes. In the common property context, therefore, the information contained in the probability distributions defining joint actions has value precisely because they allow (Second-Best) optimal decisions to be defined for each agent sharing the commons.

The key point emerging from this analysis is that common property externalities are directly related to expectations formation and the role of nonprice information in establishing these expectations over time. This result has been explored in some detail in the literature on rational expectations forecasts. In the example above, a "rational expectations equilibrium" (in the sense of Muth, 1961) would result when each agent correctly assessed the likely behavior of other agents based on available information concerning the objective probability distribution of outcomes and the relevant, correct economic theory. This forecast would lead, in turn, to a solution to the optimization problem based on a correct estimate of the equilibrium value $\bar{y}$.

Recent criticisms of the rational expectations assumption, which are highly relevant to the common property case, emphasize the difficulties of obtaining this forecast based on price information alone. As Frydman and Phelps (1983) observe, the key requirement determining the structure of joint expectations held by agents about one another is some form of "consensus condition". This consensus can only be achieved by social institutions that "rationally solve the conjectural interdependence that cannot be left simply to the rational expectations of individual agents" (Leijonhufvud, 1983).

Common property externalities are thus fundamentally an institutional issue, in which the relative capacity of institutions to assure a particular pattern of joint action over time is of paramount importance. This assurance is a function of the relative success that different institutions achieve in enforcing and maintaining consensus. This linkage between nonseparable decisions and the role of social institutions was anticipated by Marchand and Russell's (1973) analysis of liability rules and resource allocation, which showed that where externalities are nonseparable (as in the commons) the allocation of resources depends on the capacity of the legal framework to define liability. This liability assignment is a central feature of institutional success in the generation of a "consensus" concerning the likely actions of others.

The central conclusion emerging from this analysis is that "commons dilemmas" arise from the incapacity of individuals to coordinate their expectations according to rules that lead to collectively optimal outcomes. The primary difficulty is in developing the institutional or technical capacity either to reduce the external effect resulting from common use so that it is Pareto-irrelevant, or to establish a basis for predicting this effect, allowing the Second Best optimization problem to be solved. In either case, there can be no presumption that either the price system or a unique institutional prescription (e.g., private property rights) will lead to the solution to this dilemma, unless such a structure of rights can be proven superior at coordinating the expectations of the group sharing the commons.

IV. Conclusion: Future Directions for Research

I have argued that "commons dilemmas" arise from incompatible individual and group incentives. This incompatibility is formally equivalent to the differences between individual and collective rationality arising in cases of public goods (here bads) which is in turn a special case of externality. When the constraints imposed by interdependence are traced to their sources, they raise basic questions concerning the information set held by agents sharing a common resource, and the role of social institutions in establishing a consensus over how these resources are used.

The consequences of this dilemma for natural resource economics are several. First, it suggests a shift in attention at both the theoretical and empirical level toward institutional analysis. The relative capacity of different resource regimes successfully to convey information to agents who depend on jointly produced outputs will determine the relative efficiency with which these outputs are produced. This raises anew fundamental issues of the appropriate level at which non-market decisions should be made, and the best way in which to enforce these decisions over time. Second, it suggests the close linkages between several bodies of economic theory, notably those dealing with externalities, public goods, games, and uncertainty. These theoretical approaches are united by the central role of expectations formation in non-separable decision making. Rather than working to refine any one of them, however, natural resource economics may profit from combining and synthesizing them to suit actual problems. An important role for the resource economist is to make economic analysis more relevant, as well as more rigorous. Finally, the approach developed here suggests the central role of liability, and implies that a theoretical framework (e.g., Coase, 1960) in which information costs play no role can be of only limited utility. The particular advantages of institutional alternatives in efficiently and equitably allocating resources emerges from the "commons dilemma" as the central problem for future research in natural resource economics.

Footnotes

1. It should be noted that the problem was recognized by authors rather early in Western civilization. In *Politics*, for example, Plato observed: "that which is common to the greatest number has the least care bestowed on it," because "everyone thinks chiefly of his own, hardly at all of the common interest." Hobbes' *Leviathan* results from a similar dilemma, in which a strong state is needed to overcome the anarchy resulting from purely individualistic choice. Hume describes the dilemma in the *Treatise of Human Nature* in terms of draining a common meadow, in which "each seeks a pretext to free himself of the trouble and expense, and would lay the burden on others." Rousseau raises it in connection with a collective stag hunt that fails when a hunter foregoes the larger quarry in order to shoot a hare: "having obtained his prey, he cared very little about having caused his companions to miss theirs." These and other examples are discussed in Taylor (1976) and Hardin (1982). Their most forceful modern exposition is Mancur Olson's (1965), which explicitly recalls Hume's example. Other modern treatments outside the economics literature are Dawes (1980) and Edney (1980).

2. The exposition here follows Dasgupta (1982), although Figure 3 below corrects a slight error found in Dasgupta's graphical exposition.

3. This collective incentive (reflected by the shadow value associated with the constraint in the model above) is, of course, balanced by the information and transactions costs of collective action as the group grows in size. This is the essential contribution made by Olson in his classic 1965 study.

Axelrod, R., and W. D. Hamilton, "The Evolution of Cooperation," Science 211(1981):1390-96.

Barry, Brian, Political Argument, London, Routledge and Kegan Paul, 1965.

Baumol, W. J., "It Takes Two to Tango, or Sind 'Separable Externalities' Überhaupt Möglich?", Journal of Political Economy 84(1976):381-87.

Bromley, Daniel W., "Land and Water Problems: An Institutional Perspective," American Journal of Agricultural Economics 64 (December 1982):834-44.

Coase, R. H., "The Problem of Social Cost," Journal of Law and Economics 3 (October 1960):1-44.

Cornes, Richard and Todd Sandler, "On Commons and Tragedies," American Economic Review 83(4) (September 1983):787-792.

Dasgupta, Partha, The Control of Resources, Oxford: Basil Blackwell, 1982.

Davis, O. A., and A. B. Whinston, "Externalities, Welfare, and the Theory of Games," Journal of Political Economy 70(1962):241-62.

Dawes, R. M., "Social Dilemmas," Annual Review of Psychology 31(1980):169-93.

Demsetz, Howard, "Toward a Theory of Property Rights," American Economic Review 57(1964):347-59.

Edney, J., "The Commons Problem: Alternative Perspectives," American Psychologist 35(1980):131-50.

Frydman, R. and E. S. Phelps, eds., Forecasting and Aggregate Outcomes: Rational Expectations Examined, Cambridge: Cambridge University Press, 1983.

Hardin, Garrett, "The Tragedy of the Commons," Science 162(1968):1243-48.

Hardin, Russell, Collective Action, Baltimore: Johns Hopkins University Press, 1982.

Hayami, Y., and V. W. Ruttan, Agricultural Development: A Global Perspective, Baltimore: Johns Hopkins University Press, forthcoming, 1985.

Hurwicz, L., "On Informationally Decentralized Systems," in C. B. McGuire and R. Radner (eds.), Decision and Organization, Amsterdam: North Holland, 1972.

Leijonhufvud, Axel, "Keynesianism, Monetarism, and Rational Expectations: Some Reflections and Conjectures," in Frydman and Phelps (eds.), Forecasting and Aggregate Outcomes: Rational Expectations Examined, Cambridge: Cambridge University Press, 1983.

Lipsey, R. G. and R. K. Lancaster, "The General Theory of the Second Best," Review of Economic Studies 24(1956-57):11-32.

Marchand, J. R., and K. P. Russell, "Externalities, Liability, Separability, and Resource Allocation," American Economic Review 63(1973):611-20.

Mishan, E. J., "The Postwar Literature on Externalities: An Interpretive Essay," Journal of Economic Literature (1971):1-27.

Muth, J., "Rational Expectations and the Theory of Price Movements," Econometrica 29(1961):315-35.

Olson, M., Jr., The Logic of Collective Action: Public Goods and the Theory of Groups, Cambridge, MA: Harvard University Press, 1965.

Runge, C. F., "Common Property Externalities: Isolation, Assurance and Resource Depletion in a Traditional Grazing Context," American Journal of Agricultural Economics 63:4(November 1981):595-606.

Runge, C. F., "Common Property Externalities: Isolation, Assurance and Resource Depletion in a Traditional Grazing Context: Reply," American Journal of Agricultural Economics 64:4(November 1982):785-88.

Runge, C. F., "Institutions and the Free Rider: The Assurance Problem in Collective Action," Journal of Politics 46(February 1984a):154-81.

Runge, C. F., "Common Property and Collective Action in Economic Development," Paper prepared for the National Academy of Sciences, Panel on Common Property, April 1984b.

Samuelson, Paul A., "The Pure Theory of Public Expenditure," Review of Economics and Statistics 36(1954):387-89.

Shubik, Martin, "Game Theory, Behavior and the Paradox of the Prisoners' Dilemma: Three Solutions," Journal of Conflict Resolution 14(1970); 181-93.

Stigler, G. J., "The Economics of Information," Journal of Political Economy 69(June 1961):213-25.

Taylor, Michael, Anarchy and Cooperation, London: Wiley, 1976.

Von Weizcacker, C. C., "Notes on Endogenous Changes of Tastes," Journal of Economic Theory 3(December 1971):345-72.