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THE NATURE OF COMMON-POOL RESOURCE PROBLEMS

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I. INTRODUCTION

A large, multidisciplinary literature focuses on the problems occurring when multiple individuals concurrently use common-pool resources such as fisheries, grazing areas, airsheds, oil pools, and irrigation systems (see, for example, National Research Council, 1986; G. Hardin and Baden, 1977; McCay and Acheson, 1987; Haefele, 1974). Some scholars presume that all such problems share a single underlying theoretical structure -- that of an iterated, Prisoner's Dilemma game or of a collective action problem. Others have used more specific models, such as those of rent dissipation and technical externalities, to analyze these problems. On the other hand, many descriptions of the problems faced by individuals using common-pool resources do not rely on any theoretical structure to organize empirical research or test hypotheses. It is possible to learn from these descriptions about a wide variety of institutional arrangements that the users of common-pool resources have devised to change incentives and avoid the predicted theoretical outcomes. The institutional arrangements used to enable multiple users to manage common-pool resources are so diverse, however, that it is hard to imagine that they are all directed at helping individuals solve exactly the same set of problems.

We began to work on "the" problem of the commons several years ago, only to discover that what we had thought was a well defined problem turned out to be a family of closely related, but none-the-less analytically separate problems. (See Godwin and Shephard (1979) for an earlier discussion of the multiplicity of problems in CPRs.) For example, in some instances, problems faced by multiple users of a common-pool resource turn out to be familiar problems -- such as the assignment problem that has led to a structured inquiry in many other settings such as labor markets, college admissions, and marital relations. Other problems involve situations that parallel those of pure collective goods where the free-rider strategy can easily dominate the choices made by participants leading to under or no provision of a desired benefit.

We began to discover the full scope of the multiple subproblems involved in the use of common-pool resources as we developed a research agenda which focused on two distinct, but complementary, forms of empirical investigations: (1) the measurement of structural variables, strategies, and outcomes in natural settings and (2) the construction of experimental common-pool environments in a laboratory setting. Our central question was how various types of institutional arrangements and individual incentives used in relation to inshore fisheries, irrigation systems, and groundwater basins exacerbated or ameliorated collective action problems in these settings.

The attempt to develop testable models to explain patterns of strategies and outcomes observed in natural settings as well as constructing similar experimental settings forced us to be precise in defining the structure of the problems we were going to measure or test. The rent dissipation problem analyzed in the literature on fisheries (Gordon, 1954; Smith, 1968; Bell, 1972) had a mathematical structure with a close affinity (but not equivalence) to an iterated Prisoner's dilemma. We also observed fishery cases where the process of rent dissipation was apparent as well as those where the rules used by the fishermen had enabled them to avoid this problem. When we closely analyzed one of the more successful cases, where the fishermen had devised rules to prevent loss of profits, we found that the rules that the fishermen had devised in this case dealt primarily with an assignment problem (see Berkes, 1986a, 1986b; E. Ostrom, 1988). Some fishing spots are far better than others in which to harvest fish. The conflict and uncertainty engendered in fighting over the better spots raised production costs above those needed simply to harvest the fish. When we developed a theoretical model in order to examine the effect of diverse rules on the damage caused by fighting and on transportation costs, we developed an assignment game as our base model (see Gardner and E. Ostrom, 1987). The mathematical structure of this game is considerably different from that of a Prisoner's Dilemma.

Further, we discovered that while assignment problems were frequently encountered in irrigation systems, that an equally important problem is maintaining the irrigation system itself over time. Decisions made today affect the operation of the system itself in the future. Time dependence is also an important attribute of the problems involved in the potential destruction of a fishery or of a groundwater basin. Most analyses of iterated games assume that the payoff structure remains constant over time. But to adequately characterize maintenance or destruction problems, one needs to examine time dependant payoff structures rather than simple iterated games.

The need to bring conceptual order to the diverse types of problems loosely referred to as the "commons problem" occurred as we designed our first experiment. Our hope was to build a "baseline" experiment (or a set of baseline experiments) that could then be modified over time in a cumulative way. First, we wanted to create the simplest possible exemplar of a type of situation. Next, keeping the basic structure of that situation in tact, we wanted to introduce factors that would enhance or detract from the ease with which respondents in a lab would be able to achieve an optimal level of payoffs at the group level. We perceived these factors as not affecting the _kind_ of situation we were constructing but rather the _difficulty_ involved in this kind of situation. Our next step would be to tie the "base situations" to one another in a cumulative fashion if that were possible. In other words we wanted to know how assignment problems related to rent dissipation problems and time-dependant resource destruction problems. In that way, we hoped that both our theoretical and empirical results would cumulate.

We are now well embarked on our research program. We have completed several formal models, conducted initial baseline experiments, and are undertaking parallel research in natural settings. We have found the way that we have classified common-pool situations to be fruitful in organizing our own research and understanding. We think that it is also a useful device for organizing the work of others in this field and enhancing the cumulation of research findings. It is not possible in our individual papers to do more than allude to the general conceptual frame of our overall strategy. Thus, in this paper we focus on the conceptual analysis that underlies many of our own and others on-going work related to the study of common-pool resources (hereafter CPRs).

The remainder of the paper is organized as follows. In section II, we formalize a minimal set of conditions for defining what we see as necessary conditions for a commons dilemma. Section III illustrates several examples of how previous authors have framed, modelled or investigated a subset of the problems encountered in commons environments. In section IV, we develop a nomenclature and framework for what we view to be a useful way of organizing the complex set of interrelated problems related to the use of CPRs. An example of parallel field and laboratory work is discussed in section V. Final remarks are offered in section VI.

II. CONDITIONS NECESSARY FOR A COMMONS DILEMMA

Common-pool resources are defined to be sufficiently large natural or man-made resources that it is costly (but not necessarily impossible) to exclude potential beneficiaries from obtaining benefits from their use. As a result of the work of scholars such as Garrett Hardin (1968), Mancur Olson (1965), Scott Gordon (1954) and others, many presume that when individuals use such resources jointly, each individual is driven by an immutable logic to withdraw more of the resource units (or invest less in the resource) than is optimal from the perspective of all of the users. Individuals jointly using a CPR are presumed to face a tragic situation in which their individual rationality leads to an outcome that is not rational from the perspective of the group. We classify this behavioral result as a "CPR dilemma."

Let us clearly specify what assumptions are necessary to produce a CPR dilemma.

Condition 1: Resource Unit Subtractability

The presence of a CPR that makes available a flow of resource units over time that are subtractable, in the sense that a resource unit withdrawn or harvested by one individual is not fully available to another individual. Examples of CPRs and their resource units include: i) A groundwater basin and acre-feet of water; ii) a fishing grounds and tons of fish, iii) an oil field and barrels of oil pumped.

It is important to distinguish between the resource as a stock and the harvest or withdrawal of use units as a flow (see Blomquist and E. Ostrom, 1985). This distinction is especially useful in connection with renewable resources, where one can define a natural replacement rate. There', as long as the withdrawal rate does not exceed the natural replacement rate, the resource will not be exhausted. When a resource has no natural replacement (exhaustible resource), then any withdrawal rate will lead to exhaustion.

Condition 2: Multiple Appropriators

More than one individual or team of individuals are withdrawing or harvesting resource units from the resource. Following Plott and Meyer (1975) we call the process of withdrawing units "appropriation" and we use the term "appropriators" to refer to the individuals or teams of individuals who are appropriating units.

Condition 3: Suboptimal Outcomes

The strategies of the appropriators, given a particular configuration of the physical system, technology, rules, market conditions, and attributes of the appropriators, leads to suboptimal outcomes from the perspective of the appropriators.

Condition 4: Constitutionally Feasible Alternatives

Given existing institutional and constitutional arrangements, at least one set of coordinated strategies exist that are more efficient than current decisions and are "constitutionally feasible." That is: (i) a set of strategies exist in which total discounted benefits exceed total discounted costs including production, investment, governance, and transaction costs and (ii) given existing rules for institutional change, there exists a necessary consensus for such a change. A sufficient (but not necessary) condition for such a set of feasible alternatives would be the existence of a Pareto Optimal set of coordinated strategies which are individually advantageous to all appropriators or potential appropriators.[1]

Conditions 1 and 2 and the definition of a CPR are necessary to create what we call a CPR situation. Condition 1 distinguishes between situations that are public good situations and those that are CPR situations.

Conditions 3 and 4 distinguish a CPR dilemma from a simple CPR situation. If suboptimal outcomes are not produced for at least one combination of the physical system, technology, rules, market conditions, and attributes of the appropriators, there is nothing problematic in the situation. If no alternative set of constitutional feasible strategies (given discounted benefits and costs) would produce both a better outcome for the appropriators or for the group of current and potential appropriators, there is no dilemma.

III. PREVIOUS ANALYSES

Many analysts presume that all CPR situations are also CPR dilemmas and can be best represented by the Prisoner's Dilemma (hereafter PD) game or the general problem of the logic of collective action (Olson, 1965). Given these representations of the situation, it is presumed that the participants themselves, unless they are in a very small group, coerced, or offered positive side-payments will not voluntarily adopt alternative strategies. While theorists are almost unanimous in their pessimism about the likelihood of endogenous solutions to PD games, they divide into two camps when it comes to proposed solutions (E. Ostrom, 1987; 1988). One camp strongly advocates turning to a central government to impose a solution on those who use CPRs. The PD game has repeatedly been used as the foundation for the creation of a strong, central state. The other camp vigorously advocates imposing private property rights on the users. It is presumed that by dividing the commons into small chunks of private property that individual incentives will be changed to produce optimal outcomes.

In presuming that all CPR situations are CPR dilemmas and are best represented by the PD game, several errors are made.[2] One mistake is the presumption that whenever multiple appropriators withdraw subtractable units from a CPR (Conditions 1 and 2), that suboptimal outcomes will occur (Condition 3). There are many CPRs in the world which meet Conditions 1 and 2 and do not meet Condition 3. In some CPRs, the quantity demanded of the resource unit in a particular environment is not high enough to induce appropriators to pursue individual strategies that produce suboptimal outcomes. Such situations are not problematic in nature even though they might become so if either the demand for the resource unit were to increase or the cost of appropriating the units were to decrease substantially.

In other CPRs, the quantity demanded of the resource unit in the environment is sufficiently large so that appropriators would be motivated to pursue individual strategies that produce suboptimal outcomes if they did not adopt coordinated strategies. By a coordinated strategy we mean a feasible strategy adopted by each appropriator regarding how much, when, where, and with what technology to withdraw resource units and how much and/or when to invest in supply or maintenance inputs taking into account the past, concurrent and anticipated actions of other appropriators. Two types of coordinated strategies may occur.

One type of coordinated strategies is the result of an evolutionary or learning process whereby appropriators eventually reach and maintain a set of individual strategies that increase joint (and individual) payoffs relative to the suboptimal outcomes that would have existed without the evolved or learned strategies. The second type is the result of a self-conscious effort to change the institutional rules-in-use affecting the structure of the situation so that individual incentives operating within the reformed structure avoid the suboptimal outcomes for the participants. In other words, closing access and regulating use patterns by the appropriators themselves is one type of "solution" (see Ciriacy-Wantrup and Bishop, 1975). We will refer to any CPR situation that earlier met all four conditions but now only meets Conditions 1 and 2 as a **resolved CPR dilemma.**

When analysts presume that all CPR situations are automatically CPR dilemmas and must have a solution (either centralization or privatization) imposed on them by external actors, they include too many situations in their reference. **Non-problematic** CPRs and **resolved** CPRs are included as well as genuine CPR dilemmas in the sweep of their policy recommendations. If their policy recommendations are accepted, some CPR situations would be "reformed" when there is no need for a "reform" as there is no problem. Resolved CPR dilemmas may become unraveled again as the solution imposed from the outside does not take into account the prior solution evolved by the appropriators themselves. In either case, costly policies are proposed that will not accomplish their presumed objective.

Further, turning now to genuine CPR dilemmas, not all of the suboptimal outcomes produced in CPR dilemmas are the result of a set of incentives with the same structure as a PD game. Even if one limits oneself to game theoretic structures, there are multiple structures which are illustrative of incentive schemes found in subproblems within existing CPR dilemmas. For example, Michael Taylor has demonstrated for a broader class of collective action problems, many purported PD games have quite different structures including those of Chicken and Assurance games. For a 2-player, 2-strategy game to be a Prisoner's Dilemma, individual incentives require a very special pattern of payoffs as illustrated in Figure 1. For the class of symmetric-payoff matrix games, the PD game requires (a > c, b > d, d > a). Many subproblems within the context of a CPR dilemma can be represented as having this incentive structure (see R. Hardin, 1982; Dawes, 1973; and Dasgupta and Heal, 1979). On the other hand, if (c > a, b > d, a > d) the game that results is Chicken. Such a CPR situation was described by Michael Taylor:

> Consider, for example, two neighboring cultivators whose crops depend upon proper maintenance of dikes and ditches for flood control or irrigation. There is a minimum amount of work which must be done; <u>either individual alone can do it all</u>, but each prefers the other to do all the work. The consequences of <u>nobody</u> doing the work are so disastrous that either of them would do the work if the other did not (Taylor, 1987: 36).

Alternatively, if the payoff pattern is (a > c, d > b, a > d) the resulting game is one of Assurance. An Assurance game can represent many CPR situations where no one person's contribution is sufficient to gain a collective benefit but both person's contribution will produce the joint benefit. Thus, both players would prefer to contribute to the provision of a collective benefit IF and ONLY IF the other player also contributes. Otherwise, both players would prefer not to contribute at all.

As we will show later in the paper, other subproblems within CPR dilemmas can be represented by still other game structures beyond that of PD, Chicken, and Assurance games. Further, although there are strong similarities in the normal forms of many of the incentive structures found in CPR environments, the extensive form of the decision space can significantly vary. It is an important empirical question of whether strategy spaces similar in normal form, but different in extensive form, will lead to parallel observations of actual choice decisions. (See for example, Isaac and Walker (1988) for a discussion of this issue in its relation to binary choice N-person Prisoner's Dilemma games and the voluntary provision of public goods with a continuous space.)

Thus, there are several major problems with the current state of theoretical and policy oriented understanding of the problems involved in the human use of CPRs. Too many environments, that share some but not all underlying similarities, are treated as if they were fully similar. Environments that share two out of the four conditions needed for a genuine CPR dilemma are incorrectly targeted for policy reforms that may not be needed and may even be harmful interventions. Environments that share all four of the conditions needed for a genuine GPR dilemma are inappropriately represented by one general theoretical structure when several are needed to capture adequately the types of problems facing participants. It is to this latter problem that we now turn.

IV. A STRUCTURE FOR CLASSIFYING CPR DILEMMAS

While GPR dilemmas share much in common -- as is obvious from the above -- the particular analytical problem or problems that appropriators face in one CPR environment may vary rather markedly from the particular analytical problem faced by another set of appropriators using another resource. Analytically, it is quite a different task to develop a set of rules that assign fishermen to a set of fishing spots with differential returns than it is to design a set of rules to induce labor contributions by a set of common irrigators to keep an irrigation channel in good repair. The set of problems that appropriators may face can be usefully clustered into two broad types: **appropriation** and **provision** problems.

In appropriation problems, the production relationship between yield and level of inputs is assumed to be given and the problem to be solved is how to allocate that yield (or input activities to achieve that yield) in an economic and equitable fashion. Provision problems, on the other hand, are related to creating a resource, maintaining or improving the production capabilities of the resource, or avoiding the destruction of resource systems themselves. In other words, in appropriation problems, we focus attention on the flow aspect of the CPR -- in particular, authority rules defining rights to the use units of flow withdrawn or harvested by users. In provision problems, we concentrate on the stock aspect of the CPR -- including the implication of current withdrawal rates for future values of the stock, as well as other capital good features of the resource.

Appropriation Problems

Solving appropriation problems focuses on the allocation of the yield (flow) of a resource in terms of: (1) the quantity of resource units to be appropriated or the dual problem of determining the efficient level and mix of input resources necessary for obtaining that yield, (2) the timing and location of appropriation, and (3) the appropriation technologies adopted. The terms "rent dissipation," "assignment problems," and "technological externalities" are regularly used in the economics literature to differentiate these problems.

Rent is dissipated when private investments made in appropriation activities are greater than economically optimal. Evidence of a rent dissipation problem include over-capitalization, too many appropriators, or too large a harvest rate (or combinations of these three). The work of scholars such as Agnello and Donnelly (1975), Bell (1972), Christy and Scott (1965) and Gordon (1954) is directed toward behavioral decisions which belong to this category. Lack of clarity or inappropriate assignment of appropriations to spatial or temporal slots leads to outcomes such as conflict and violence and increased production and transaction costs (see Gardner and E. Ostrom, 1987; Gale and Shapley, 1962). Robert J. Barro and Paul M. Romer (1987) discuss a variety of assignment problems including those associated with ski-lift pricing, open-access fisheries, and the determination of rooms for professional meetings. Technical externalities occur when the presence of some users or their technologies increase production costs for other users. Appropriation problems can be conceptualized as either one-shot static situations or as iterated, time-independent situations. Thus, our classification scheme separates appropriation problems from alternative forms of dilemmas which are concerned with increasing or decreasing the productive capabilities of the resource over time. In its most fundamental form, appropriation deals simply with the problem of equating the marginal costs of appropriation with the marginal returns from appropriation.

A. Rent dissipation - The most basic appropriation problem is rent dissipation, since rents are dissipated whenever the marginal returns from an appropriation process are not equal to the marginal costs. The simplest model of rent-dissipation assumes homogeneous appropriators, resource units spread across space in a homogeneous fashion, and the use of a homogeneous technology. The logic of rent dissipation follows from a behavioral assumption that marginal appropriators of the resource will ignore the impact of marginal investments on the return of intra-marginal investments. It follows that such strategic behavior will yield an outcome in which inputs are invested as long as the average return from the investment exceeds the marginal costs of such investments. See Gordon (1954) for one of the earliest expositions of this dilemma and the work of such authors as Johnson and Libecap (1982) for more recent discussions.

B. Assignment - Changing the assumption regarding the spatial characteristics of the resource units creates an assignment problem. Many fishing grounds, for example, are characterized by "fishing spots" which may vary dramatically in terms of their yields. Farmers who may take water from a location on an irrigation canal near the head of the system may obtain much more water for their effort than farmers who must take water from a "tail-end" position.

The simplest example of the assignment problem is the following game. The CPR, say a fishery, consists of two spots of known value vi, vl > v2. There are two users. A user may utilize either spot, but not both simultaneously. The resulting 2-player noncooperative game is portrayed in Figure 2. The payoffs assume that two users using the same spot catch the same amount each. For v1 > 2(v2), each user has a dominant strategy, to use spot 1. Thus a unique equilibrium point exists, with both users on the best spot. For v1 = 2(v2), there is a continuum of equilibrium points, but only the equilibrium with both players on the best spot is perfect. For v1 < 2(v2), neither user has a dominant strategy. In this case, there are three equilibrium points. Two of these, with one player at each spot, are even efficient arrangements. However, neither of these is likely to emerge in an open-access CPR. Much more likely from the standpoint of Harsanyi-Selten selection theory is the equilibrium point in mixed strategies. Only part of the time is there a user on each spot, and both payoffs are equal. Thus, none of the equilibria we expect to be played in the parameter space (v1, v2) are social optima. All could be improved upon by coordinated strategies of one kind or another.

Irrigation systems around the world have to cope with assignment problems. Those that are managed by local irrigators and do so with little conflict have developed effective rules for assigning time slots to different irrigators. Messerschmidt (1986: 463) describes one such system in the following way:

> To make distribution equitable for all farmers over the course of the year, the barley crop was watered from the top of the north fields downward; that is, the fields closest to the head received first water. For buckwheat, the watering order was reversed so that the farther fields were watered first. This traditional rule was remembered in a Thakali rhyme: _kar vaalaa. nhaa mhalaa_, meaning 'barley from the top, buckwheat from the bottom'.

C. Technological externalities - Changing the assumption regarding the presence of a homogeneous technology creates a technological externality problem when the use of one technology increases the costs for the users of other technologies. For fishing trawlers to be able to operate efficiently, for example, these boats need to be able to travel over a fairly large domain. Fixed nets and trawlers operating in the same territory increase the operating costs for both types of production technologies. Similarly, if one group of fishermen begin to use dynamite in their fishing efforts the costs for other fishers rise as a result of this production technology (cite). Many fishing communities have established extensive rules allocating space within a fishing grounds to different types of technologies at different seasons of the year so as to reduce the external costs. A well-documented case of the use of these kinds of rules to cope with problems of technical externalities in the fishing village of Fermeuse, Newfoundland was written by Kent Martin (1979).

We can think about the linkages among appropriation problems as illustrated in Figure 3. Rent dissipation is the underlying behavioral dilemma. The form of rent dissipation varies within specific CPR environments as internal variables such as spatial heterogeneity or technological heterogeneity are varied.

Provision Problems

Analyses of provision problems begin at the conceptual level of the optimal size and productive nature of the resource itself (the stock). Provision problems focus on the behavioral incentives for appropriators to: (a) contribute resources for the provision or maintenance of a CPR, supply side provision or; (b) alter appropriation activities within an existing system in such a manner as to change the withdrawal patterns from the CPR so as to maximize multiple period returns or even possibly avoid the extinction of a biological resource, demand side provision.

The supply side dilemma faced in CPR environments is one of provision of the resource itself and/or maintenance of the resource. The classic supply side provision problem found in the CPR literature is that of the maintenance required to keep an irrigation system operating appropriately (see Coward, 1980; Chambers, 1977; and Easter and Welsch, 1986 for analyses of this problem). Martin and Yoder (1983) provide an in-depth description of the extensive efforts that local farmers have undertaken in the mountainous areas of Nepal to build and maintain their own irrigation canals as well as the rules they use to insure the continued maintenance of these systems. De los Reyes (1980) provides similarly detailed accounts of how 47 different communal irrigation systems in the Philippines have been able to keep locally constructed irrigation canals in good working order.

Conceptually the supply side CPR dilemma links directly with the theoretical and empirical literature focusing on public goods provision. However, it is important to note that although the incentives of individuals in a supply side CPR provision problem may in part parallel those of provision of a pure public good, the physical characteristics of the CPR resource and its yield do not in general take the form of a pure public good. Parallel to pure public good provision, in an open access CPR, free riding may be possible in maintenance or provision since it may not be economically feasible to monitor. In general, however, a CPR resource and its yield are not characterized by pure non-rivalry (subtractability) in consumption (see Nitzan, 1988).

The classic problem on the demand side is the maximization of discounted present value of returns and/or extinction of biological species as a result of an appropriation rate higher than the minimal safe yield for the resource. This form of the CPR dilemma has been theoretically modelled under varying assumptions by authors such as Clark (1976) and Smith (1968). At the empirical level, the demand side provision problem is conceptually the choice problem investigated in earlier experimental research such as Brechner (1976), Cass and Edney (1978), Jorgenson and Papciak (1980), Messick and McClelland (1983), and Messick, et al. (1983). In these experiments, subjects face a general problem of appropriating resources from a common pool whose regenerative powers depend on the stock of existing resources. Blomquist (1987) and Blomquist and E. Ostrom (1985) describe the problems faced by a group of water producers utilizing groundwater basins located adjacent to the ocean. When water withdrawn exceeds the average safe-yield of the basin, salt-water intrudes along the coast destroying the capacity of the basin to hold potable water into the future. To replace the reservoir functions of groundwater basins in Southern California is extraordinarily expensive. Thus, the "provision" problem facing the producers is one of reducing their current withdrawal of use units from the resource itself, in order to be sure to provide the resource over a longer time period.

To illustrate a demand side provision problem, suppose that fish are distributed homogeneously spatially and the entire population at time t is $x(t)$. An individual fisher's strategy is to harvest $h_i(t)$. Fish population dynamics satisfy:

$$x(t + 1) = f[x(t)] - \sum_{i}^{n} h_i (t),$$

if there are n fishers. The term f[x(t)] represents natural increase. If

$$f[x(t)] < \sum_{i}^{n} h_i (t),$$

then, the population is falling each period and may collapse. Along such a path, payoffs (harvests) will also be falling period after period.

Depending on the specific characteristics of the dilemma in question, provision problems may strategically take any of these forms: one-shot games, time-independent repeated games, or time-dependent repeated games. For many CPR dilemmas, the most natural representation is a time-dependent repeated game. One-shot games or time-independent repeated games are adequate representations when the natural replacement rate is at least as great as current and foreseeable withdrawal rates and the CPR is otherwise able to maintain itself. The CPR is practically inexhaustible. In the case of a CPR dilemma, this condition is generally not met and one is forced to deal with the time-dependent features of the situation. In time-dependent situations, appropriators face an environment in which the strategies they have undertaken in time periods t-1, t-2, . . . affects the strategies available to them in time periods t, t+1, t+2, . . . Time dependant provision problems can be arrayed as in Figure 4.

The Relationship Between Appropriation and Provision Problems

In natural settings, individuals frequently face combinations of appropriation and provision problems. For analysis, however, it is possible to treat them as separate problems in order to gain a clearer understanding about what is involved in reducing the severity of each of these problems. Appropriation problems are an easier class of problems to analyze. Further, there are many problems that appropriators face in CPR dilemma situations which are strictly appropriation problems and do not involve either a demand side or a supply side provision problem. While it is possible to analyze provision problems apart from appropriation problems, in natural settings they will tend to occur together. It is hard to imagine a set of appropriators who are facing a provision problem in a natural setting who do not also face an appropriation problem.

V. Empirical Verification: Rent Dissipation in the Field and Lab

The nomenclature and theoretical structure discussed above defines a framework for distinguishing between the multiple complex decision problems found in CPR environments. Empirical evidence is necessary for drawing conclusions regarding the role of institutional arrangements and/or environmental parameters in determining the degree of severity. Our empirical work is following two separate but complementary avenues. First, we are currently involved in the coding of in-depth case studies written by anthropologists, agricultural economists, sociologists, human ecologists, and others about the human use of CPRs. In this empirical effort, we are extracting structured data from qualitative narratives as well as from tables of data presented by the authors of case studies.

With varying degrees of success, we can measure and analyze the role of many important structural variables as they occur together in natural settings. We cannot control, however, for the variables we wish to examine in more detail. We are dependant upon prior authors having found particular cases with variables in particular configurations and having recorded them in such a manner as we can use them. For this reason, our second empirical effort is based upon the design of a series of CPR experiments. This methodology allows us the flexibility of structuring the decision environment and incentives according to the specific theoretical constructs we wish to examine. Since appropriation problems can occur alone or in combination with provision problems, our series of experiments have begun by focusing first on appropriation problems. Below, we summarize the results of two complementary studies: (i) an interesting field example demonstrating rent dissipation in the form of over capitalization and (ii) summary results from our initial set of experiments designed to investigate rent dissipation in a baseline open access environment.

The Sri Lanken Fishery

Alexander (1982) documents a tragic case of rent dissipation in a Sri Lankan, inshore fishery where expensive beachseines are the dominant form of equipment used to harvest fish (see E. Ostrom, forthcoming, for a more detailed summary of this case study). This study is of special interest since it describes the dynamic adjustment from a partially solved CPR dilemma to one of failure, which corresponds closely with changing rules, as well as with changing market and demographic conditions. (See Thomson, Feeny, and Oakerson, 1986, for a discussion of the evolution and dissolution of common property systems.) Below, we outline the sequence of events.

The field study focuses on the overuse of beachseines in a small fishing village (population approximately 300). During the early 1900s the fisherman of this village had collectively devised a relatively complex rotation scheme for allocating use patterns of approximately 20 jointly owned beachseines in the village. With this number of nets the villagers produced a relatively stable and profitable income. Since nets were so expensive (a beachseine has a use life of approximately 5 years, with cost of procurement equal to approximately 3 times the average household's annual income) and at least eight men were necessary to haul the net, ownership of a single net was divided into eight shares. Each worker worked his own share and divided his catch equally with the other seven owners. Shares were tradeable to village members.

The stability of the set of rules and the efficiency of resultant outcomes diminished over time for several key reasons. From 1901 to 1931, the village population increased by 70 percent, leading to considerable pressure to increase the number of nets. Given that access to the fishery was defined with respect to a rotation scheme of nets (nets actually had names and were allocated a spot in the rotation sequence accordingly) and that ownership of a single net corresponded optimally to eight persons, there was significant motivation to acquire new nets. Alexander explains:

> If there are twenty nets, a man with one share will receive 1/160th of the annual catch. But if after his death his two sons take joint

> ownership of his share, they each receive only 1/320th of the catch, whereas if one joins in the construction of a new net they each receive 1/168th (Alexander, 1982: 204).

Second, in 1933 the government of Ceylon passed legislation: (1) limiting the number of beachseines, (2) requiring registration, and (3) opening the ownership of shares to individuals <u>outside</u> of the village. The government, however, did not enforce the first aspect of the legislation limiting the number of nets to the number in use in 1933, but did encourage outsiders to fish in the village. A third set of factors upsetting the prior situation was that a road was constructed in the 1940s from the village to a marketing center, an ice factory was constructed nearby, and the price of fish increase by approximately 400 percent. By 1945, 71 nets were in operation.

At first the operation of the increased number of nets were very profitable (increased prices had increased average revenues per share) but evidence exists that (at the fishery level) the marginal product of additional shares were negative. New entrepreneurs entered the market, with shares worked by wage laborers. By purchasing shares which were separated in sequence in the beachseine rotation scheme, entrepreneurs controlled for the risk of a "bad" catch during any one rotation of one of their net shares. In periods of low harvest, share holders without adequate variance of their sequence in the rotation scheme, risked the possibility of below subsistence income. Alexander computed the optimal number of shares within the rotation scheme to be 6.5. In 1971, 58 percent of the fisherman owned less than 5 shares.

During the next decade the ownership pattern of shares shifted further from that of village control to open access. Attempts by the fishermen to have the government enforce net restrictions went unheeded until 1946. At this time the government agreed to enforce a restriction of 77 nets. Over the next two decades, however, the enforcement was lax and more nets were added. By 1966, the number of nets (and a new government limit) had increased to 108.

In summary, the changing external rules, market, and demographic conditions had led to the virtual collapse of a collective institution which had earlier successfully monitored usage and restricted the degree of suboptimal use of the resource. It is not possible to get an exact measurement of the degree of over capitalization and rent dissipation in the resource by 1970. The following data, however, are quite illustrative. Physical conditions within the fishery suggested that 20 to 30 nets could be used optimally (nets had to be used sequentially, not simultaneously). In 1971, however, 100 nets were owned and the average net was used only seven times during the year.

It is noteworthy that the impetus to control entry into this fishery came from the fishermen themselves and the resistance to closing access was from government officials unwilling to enforce their own legislation. This runs counter to the presumption that a solution to CPR dilemmas must come from outside the group involved. While this example clearly illustrates how rent dissipation occurs in the field, it is not particularly typical of the inshore fisheries for which we have obtained detailed information (as contrasted to ocean fisheries where it is certainly typical). In many inshore fisheries, the fishermen themselves have established de facto rule systems that close access to the fishing grounds and regulate use patterns so as to reduce the risk of extreme rent dissipation (see Schlager, 1989). As part of research in field settings, we are attempting to determine the variables that are associated with the emergence of rules to control CPR dilemmas from within the set of fishermen involved.

The Laboratory Experiment

No laboratory experiment can capture the drama and complexity of a process of rent dissipation occurring in a field setting. But, by creating a base-line rent-dissipation experiment in an experimental laboratory, we cannot only test the empirical predictions of theories that predict rent-dissipation, we can eventually examine the effect of variables presumed to increase or decrease the likelihood that appropriators will change their own strategies.

The theory of rent dissipation follows from a behavioral assumption that appropriators from a CPR will ignore the impact of marginal investments on the return of intra-marginal investments. It follows that such strategic behavior will yield an outcome in which inputs are invested as long as the average return from the investment exceeds the marginal costs of such investments. Our baseline experiments were designed to test this prediction.

We interpret our experimental design as a "boundary" experiment for investigating the notion of rent dissipation in CPR environments. Groups were not extremely large (N = 8) and subjects were given explicit information on the marginal effects of investment in the CPR. To the extent that our behavioral results are contrary to predictions of rent dissipation, one is left with controllable experimental variables whose levels can be varied to search for theoretical confirmation (eg. group size, openness of the resource, investment information, etc.)- However, to the extent that our results confirm the theoretical prediction of dissipation, they are suggestive of a theory that is quite robust.

The full design and results of our baseline experiments are detailed in Walker, Ostrom, and Gardner (1988), hereafter WOG, Below, we summarize the form of the decision environment and illustrative results.

The Decision Environment

At the beginning of each experimental session, subjects were told that they would be making a series of investment decisions, that all individual investment decisions were anonymous to the group, and that at the end of the experiment they would be paid privately (in cash) their individual earnings from the experiment. Subjects then proceeded to go through, at their own pace, a set of instructions that described the investment decisions.

Subjects were instructed that each period they would be endowed with a given number of tokens (e_i). Each period they were to invest their endowment between two markets. Market 1 was described as investment opportunity in which each token yielded a fixed (constant) rate of output and that each unit of output yielded a fixed (constant) return. Market 2 (the CPR) was described as a market which yielded a rate of output per token dependent upon the total number of tokens invested by the entire group. The rate of output at each level of investment for the group was described in functional form as well as tabular form. Subjects were informed that they would receive a level of output from market 2 that was equivalent to the percentage of total group tokens they invested. Further, subjects knew that each unit of output from market 2 yielded a fixed (constant) rate of return. Subjects knew with certainty the total number of decision makers in the group, total group tokens, and that endowments were identical. They did not know the actual number of decision periods that would constitute the experiment. Subjects were separated by blinders and were not allowed to communicate.

Our experiments are divided into two parametric conditions (high and low pay) shown in Table 1. Conditions were constant within a given experiment. All experiments were conducted for at least 20 decision periods (no more than 25). As shown in Table 1, our experimental design called for inexperienced and experienced"groups. Experienced groups included subjects who had participated in any one of the previous inexperienced runs. No experienced group was comprised of an inexperienced group held intact.

Behavior in the CPR Environment

In Figures 5 and 6 we examine the observed investment decisions from two of our experiments. Plotted in the figures are period by period observations on the levels of marginal revenue product MRP (denoted o) and average revenue product (ARP) (denoted *) for the market 2 investments. Note that the hypothesis of full rent dissipation would imply investment decisions in which ARP - MC. Figure 5 displays observations from one of our high pay -- inexperienced runs and Figure 6 for one of our high pay -- experienced runs. The figures are representative of several of the summary conclusions reported in WOG.

First, across all of our 18 experiments we observed the pulsing pattern of investments across periods, where ARP is reduced to very close to MC at which time investors tend to reduce investments in market 2 and rents increase. This pattern tends to repeat itself throughout the experiment. We are not implying that we found symmetry across experiments in the magnitude of "rent peaks" or the timing of peaks. The general cyclical pattern is consistent, however, throughout our baseline experiments and in no experiment did we find a pattern in which rents remained anywhere close to maximum. For example, the maximum rent on average for any single experiment was 53.4 percent of optimum.

Second, as depicted in Figures 5 and 6, there was a general pattern for experienced subjects to begin initial periods with lower rents accrued relative to their inexperienced counterparts. Further experienced groups tended to exhibit a "tighter" pattern of investments across periods. Over all of our 18 experiments, inexperienced subjects accrued rents at an average of 42 percent of optimum compared to 30 percent for experienced subjects. We found no systematic evidence that the payoff condition (high vs low) had a significant effect on rents.

Finally, we found strong evidence that the level of rents accrued decreased with repetition of the environments. Even though we found no examples of groups that stabilized at a zero rent behavioral equilibrium. We did find systematic evidence for investments in later periods to be characterized by "lower" rent peaks and lower average rents accrued. Our experimental results roughly parallel the results found in a natural setting once open access conditions predominated.

VI. Final Discussion and Summary

Our analysis above concentrated on what my be refereed to as "across type" variation among subproblems within CPR environments. Specifically our framework allows for a conceptual dichotomy between subproblems related specifically to the flow of output from a resource (appropriation) and those related to stock aspects of the resource (provision). Within each of these conceptual subproblems, however, the degree of inefficiency must be related to the specific nature of the resource and the underlying institutional rules. It is these characteristics which ultimately defined the incentive structure faced by decision makers within the CPR environment. For example a small group of appropriators facing a rent-dissipation problem in an isolated setting where few competitors are lured to the resource and where the yield of the resource is easy to calculate and uniformly spread in time and space face a much less severe problem than a large group or a group located close to a region in economic decline or a group using a resource whose yield is highly variable in time and space. A group of appropriators who have autonomy and the institutional facilities to change their own rules may be able to resolve their own dilemmas instead of needing external reform.

Many factors affect the severity of the problem facing appropriators and the likelihood that the appropriators can evolve or learn new strategies or design new rules. Below we briefly describe five broad clusters of variables which we have found useful in organizing our empirical work. We perceive these factors as not affecting the kind of CPR subproblem we are analyzing but rather the difficulty involved within a particular subproblem. The five clusters relate to:

1. The resource and the resource units - The size and boundedness of the resource, the availability of reliable and valid information about resource conditions and yield, the ease of measuring withdrawal rates, whether resource units are stationary or fugitive, and the variability of resource units over time.

2. Production technologies and market structure - The appropriative power of the technologies used and the cost involved in using different technologies. The availability of markets for input and outputs, the stability of external markets, and the competitive structure of external markets.

3. Operational rules - What rules are actually used by appropriators to specify who has access, what actions must, may, or may not be taken individually or collectively, what conditions in the world must, may, or may not be affected, what information must, may or may not be exchanged, and what positive or negative sanctions may be attached to actions or outcomes.

4. Collective and constitutional choice mechanisms - The procedures which could be used to change the operational rules.

5. The structure of the operational action situation facing appropriators - The number of appropriators, the number and type of legal positions that appropriators can possess, the dependence of appropriators on the resource, the degree of homogeneity in terms of assets, technology, information, skills, culture, values, the actions that appropriators can take, the information that is available to

appropriators, and the payoffs that appropriators can receive. (See E. Ostrom, 1986, for a discussion of the variables involved in an action situation and related rule configurations; see, also, Oakerson, 1986, for a similar analysis.)

In summary, this paper presents a framework for conceptually organizing the multiplicity of behavioral problems encountered in common-pool resources. The structure and nomenclature we develop (and borrow from earlier work in this area) can be used to more clearly specify the context of several forms of CPR behavioral dilemma and to show the interaction between these dilemmas. Further, the framework allows for a clearer understanding for how broader theoretical constructs (e.g. prisoners dilemma, coordination games, etc.) can be used shed light on these behavioral dilemmas.

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Footnotes

1. Thus, constitutionally feasible alternatives include changes in the operational rules affecting the rights and duties of appropriators and non-appropriators accomplished by procedures authorized in the basic constitution of a political regime.

2. Dasgupta and Heal (1979: 59) pointed out a decade ago that "contrary to what is often claimed, the problem of 'the common' and the resulting sub-optimality of the market equilibrium are not formally identical to an N-person version of the prisoner's dilemma game."

Figure 1
Payoff Structure: A 2X2 Game

	s1	s2
s1	a, a	b, c
s2	c, b	d, d

Figure 2
An Assignment Game

Appropriator 1	Appropriator 2: Fish Spot 1	Appropriator 2: Fish Spot 2
Fish Spot 1	v1/2, v1/2	v1, v2
Fish Spot 2	v2, v1	v2/2, v2/2

Figure 3

Appropriation Problems

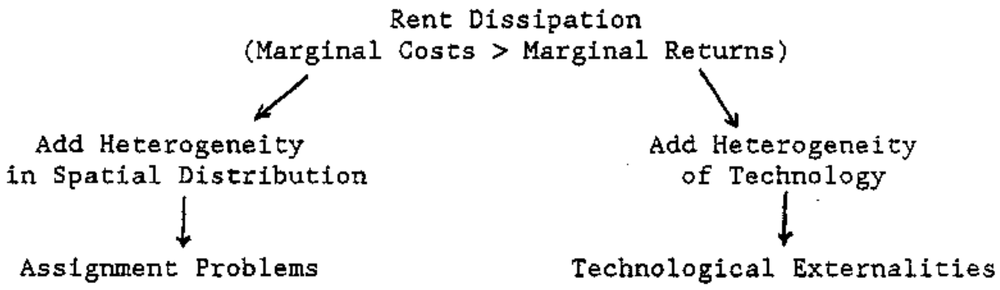


Figure 4

Time Dependant Provision Problems
Yield in Time t Depends on Strategies in Time t-1, t-2

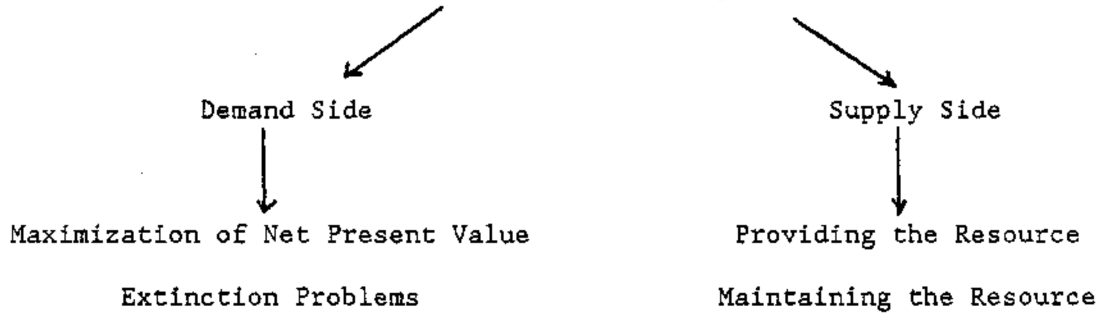


TABLE I

EXPERIMENTAL DESIGN
Parameters for a Given Decision Period

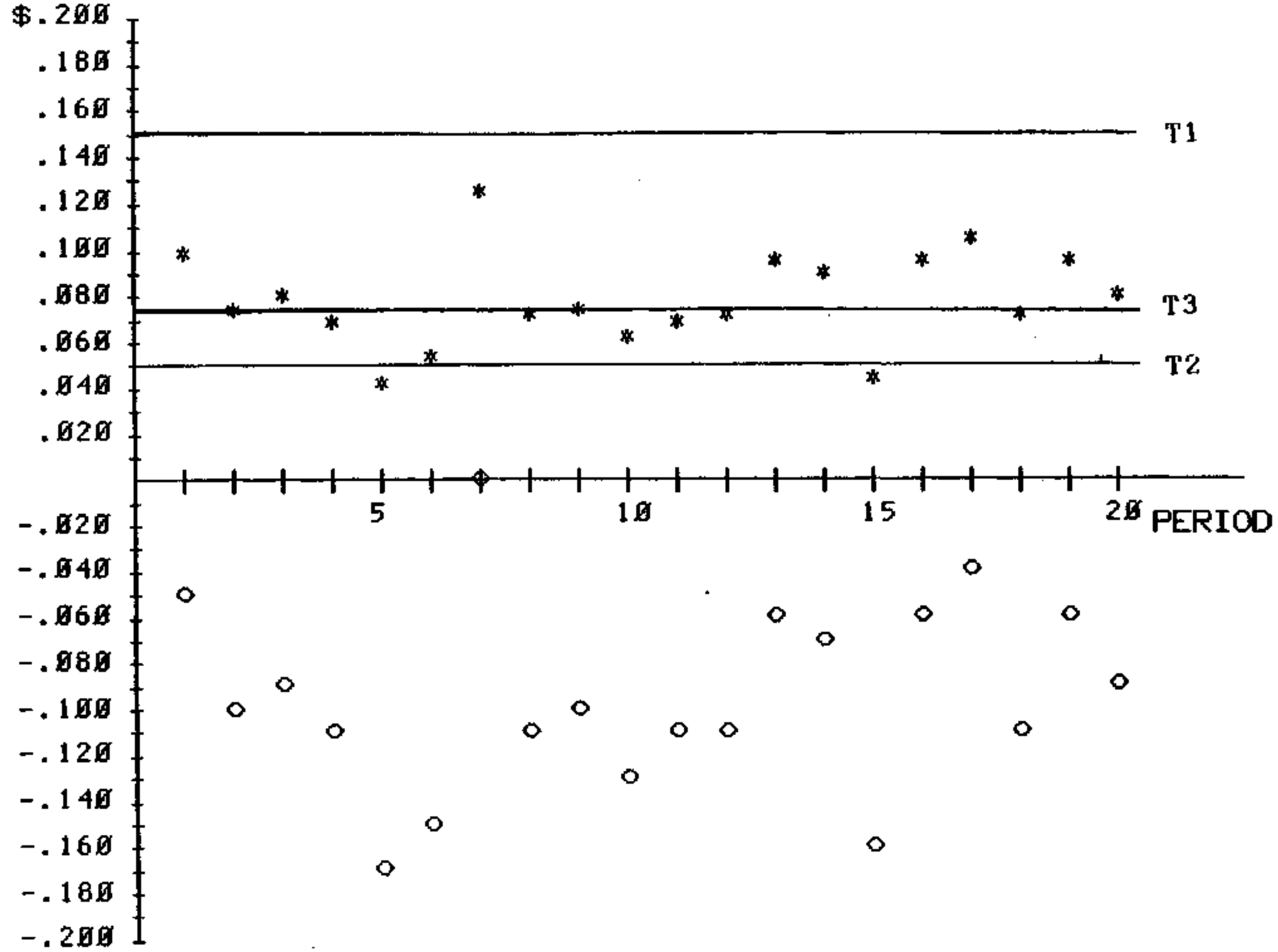
Experiment Type:	High Pay	Low Pay
Inexperienced Experiments	4	6
Experienced Experiments	4	4
Number of Subjects*	8	8
Individual Token Endowment	10	10
Production Function: Mkt.2**	$25(\Sigma x_i)-.30(\Sigma x_i)^2$	$15(\Sigma x_i)-.15(\Sigma x_i)^2$
Market 2 Return/unit of output	$.01	$.01
Market 1 Return/unit of output	$.05	$.05
Earnings/Subject at Group Max.	$.92	$.50

* In two experiments (one inexperienced and one experienced) we had only 7 subjects. In these experiments subjects received an endowment of 12 tokens.

** Σx_i = the total number of tokens invested by the group in market 2. The production function shows the number of units of output produced in market 2 for each level of tokens invested in market 2.

FIGURE 5

MARKET 2 INVESTMENTS: EXPERIMENT 4IHP
INEXPERIENCED SUBJECTS - HIGH PAY DESIGN



Legend: * - observed ARP
o - observed MRP
T1 - ARP at maximum rents
T2 - ARP at zero rents
T3 - ARP at Nash equilibrium

FIGURE 6

MARKET 2 INVESTMENTS: EXPERIMENT 1XHP
EXPERIENCED SUBJECTS - HIGH PAY DESIGN