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RULES AND GAMES

INSTITUTIONS AND COMMON-POOL RESOURCES

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This is an initial draft of the first four chapters of this book for review by others involved in writing chapters of this book and a limited number of colleagues at the Workshop. We appreciate any and all comments that colleagues can pass along.

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Rules and Games:
Institutions and Common-Pool Resources

by

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Chapter 1

Common-Pool Resource Problems and Proposed Solutions

In June, 1991, the Ocean Hound sank in thick fog just off the Dover coast taking all five members of her crew with her. This was not the first time during 1991 that a fishing ship harbored at Brixham Harbor in England had sunk. During the first six months of 1991, more than 30 fishers have been lost. Fishing is always a dangerous occupation, but something different was happening. About the same number of fishers died during the entire years of 1990 and 1989 as died during the first six months of 1991. No single cause appears to underlie the doubling of the death rate during 1991. "But on the docks of Brixham and other ports along the rugged coast of southwest England, there is talk that growing competition in the fishing grounds and hard economic times at home may be forcing some fishers to take more chances with weather and their boats" (New York Times, September 13, 1991). The Brixham fleet now numbers about 90 boats, almost twice what it was a in 1981. Monthly payments on boats have risen from $3,116 (on a $200,000 note) in 1987 to $4,250 in 1991. Fuel could cost $3,672 per week in 1991 compared with $3,128 just one year prior. Paul Jarrett, who runs the Royal National Mission to Deep Sea Fishermen—the Salvation Army of the Sea—indicated that he had been in this work "for 25 years and this is the worst period yet" (ibid.). Jarrett said that pressure to pay mortgages and bills has led fishers to put in more time and take more risks.

Across the world in California, another instance of excessive investment in a resource occurred during the summer of 1991. The generators built by Pacific Gas and Electric to tap the geothermal power at The Geysers—located 150 kilometers north of San Francisco—to produce 2000 megawatts of power were actually yielding only 1500 megawatts. Even worse, the pressure in the wells was dropping fast. It appears the underlying problem is simple. "The earth beneath those northern California mountains is running dry. As a result, the outlook for The Geysers is grim: By the mid or late 1990s, power output may slip to half its 1987 level- A $3.5 billion investment is in danger of turning into a white elephant" (Science. July 12, 1991, p. 134).

The basic problem is "overdevelopment" of a resource. Just as the fishing fleet of Brixham had jumped from 45 boats up to 90 boats within the course of a decade, the amount of capital investment in generating capacity at The Geysers doubled between 1981 and 1991 accelerated by economic incentives offered by the U.S. national government. In 1981 there were 14 generating units with a total output of 942 megawatts. By 1991, generating capacity had jumped to 2043 megawatts involving the investments of five utilities and six developers" (or developer-utility combines). "Put simply, there are too many straws in the teapot," was the graphic comment of Thomas Box of Calpine Corporation of Santa Rosa, one of the firms involved.

The incentives toward overinvestment in withdrawal capacity from fisheries and underground water resources illustrated by problems at Brixham Harbor and at The Geysers are not isolated examples of unique events. They illustrate the kinds of problems that may occur when multiple individuals rely on the same resource without rules that clearly divide what is available for withdrawal among a defined group of individuals. In these conditions individuals can be driven by strong incentives to overinvest in withdrawal activities whether they are building new ships to fish from the same fishery or sinking new wells to produce geothermal power from the same field.

These are examples of common-pool resources where the individuals involved face a dilemma. Each individual pursuing the best individual strategy, given the incentives they face, yields outcomes that are undesirable for each individual and the group as a whole. These cases are examples of a more general phenomena which we call a common-pool resource (CPR) dilemma. CPR dilemmas occur frequently but do not occur in all situations where multiple individuals use the same resource. Because the problems that occurred at Brixham Harbor and at The Geysers are repeated frequently across the world, it is sometimes thought that CPR dilemmas are inevitable and require external intervention for their resolution.

The central thesis of this book is that individuals jointly using a CPR face incentives leading to harm for themselves and others. The degree of harm depends on the rules they use and the environment in which they make decisions. We formalize this relationship using the framework of institutional analysis and noncooperative game theory. The relationship between rules and games is of fundamental importance to all of the social sciences and particularly when social science is used in policy-making. We intend to explore the general relationship between rules and games and do so by focusing on a broad family of games of considerable substantive importance—the games that appropriators play when they decide upon investment and harvesting activities related to CPRs. We begin with a formal definition for a CPR and a CPR dilemma.

A Definition of Common-Pool Resources

Common-pool resources (CPRs) are defined to be natural or man-made resources in which: (a) exclusion is nontrivial (but not necessarily impossible) and (b) yield is subtractable. Let us discuss these two attributes of our definition.

Nontrivial Exclusion

There are many sources of difficulty in excluding potential beneficiaries from using a CPR. In many cases, it is the sheer size of the CPR (the absolute cost of fencing an inshore fishery let alone an entire ocean is prohibitive). In other cases, the additional benefits from exclusion are calculated to be less than the additional costs from instituting a mechanism to control entry. In still other cases, basic constitutional considerations prevent exclusion (a constitution, for example, might explicitly provide access to the fisheries within a jurisdiction to all citizens of that jurisdiction). Further, in some cases traditional considerations, issues of fairness, ethics, etc. may preclude serious consideration of excluding some beneficiaries. Except under extreme boundary conditions, nontrivial exclusion leads to CPRs being used by multiple individuals. We refer to such users as appropriators.[1]

Resource Unit Subtractability

A CPR makes available a flow of resource units over time that are subtractable, in the sense that a resource unit withdrawn or harvested by one appropriator is not fully available to others. 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, iv) computer facilities and processing time; and v) parking garages and parking spaces. This is the key characteristic that distinguishes CPRs from pure public goods.

Our definition emphasizes the importance of distinguishing between the resource as a stock and the harvest or appropriation 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 regeneration rate. There, as long as the appropriation rate does not exceed the regeneration rate, the resource will not be exhausted. When a resource has no natural regeneration (an exhaustible resource), then any appropriation rate will lead to exhaustion. In this volume, we focus on the problems of renewable CPRs. Many of the general issues we treat, however, also apply to the problems of regulating the use of exhaustible resources such as oil pools where the problem is also one of withdrawing at an optimal rate.

The fishers and the power companies discussed above, who keep investing more and more in their resources, are led by the structure of the situation they face, to behavior that is harmful to all participants. Each individual's investment and appropriation activities affect all of them adversely. Individuals jointly using a common-pool resource are thought by many policy analysts 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 call this behavioral result a "CPR dilemma." It is not the case, however, that all appropriators sharing CPRs, necessarily face immutable tragedies. Fishers sharing inshore fishing grounds in Turkey (Berkes 1986), in Brazil (Cordell and McKean 1986), in Japan (Ruddle and Akimichi 1984), in Eastern Canada (Davis 1984) and Western Canada (Marshak, Guppy, and McMullan 1989) have all devised various rules to restrict entry and allocate access and appropriation rights so as to avoid CPR dilemmas. Groundwater pumpers in seven Southern California groundwater basins have devised complex rules to regulate appropriators so as to reduce conflict and avoid the mining of their groundwater basins (Blomquist 1992). The establishment of local rules to regulate appropriation from and maintenance of irrigation systems occurs throughout the world (E. Ostrom 1992). One example helps illustrate how rules can change" the games that irrigators play.

In the Indian village of Kandadevi, farmers long-ago devised a complex set of rules creating the position of a *neerpaichy* or water distributor. In modern times the *neerpaichys* are appointed and paid by the local farmers for a three or four month period when their local water tank (a small surface reservoir) holds water that can be used for irrigation. Anyone eligible for this position must either own or lease land below the tank. Usually a pair of *neerpaichys* irrigate together; one is a landowner while the other is a landless tenant. The process of appointing and paying the water guards and deciding how water is to be distributed is described by Nirmal Sengupta (1991, 104).

> The Kandadevi villagers usually assemble in the evening in an open ground near the temple. Here a metering is conducted and presided over by the important landowners in the ayacut. After appointing the *neerpaichys* they are taken to the temple for oath-taking to remain impartial. With this vow they break a coconut. They are paid in cash at the rate of Rs. 10 per acre per month by the cultivators. The *neerpaichys* themselves collect the money.
>
> During water scarcity in the tank, people assemble in formal meetings and decide how much of hectarage can be saved through irrigation with the remaining supply. It is then converted into some measure of land per

> holding.... Every cultivator thereafter encloses that much of an area irrespective of his total holding. The *neerpalchys* then implement the distribution to these enclosed parts.

As Sengupta notes, this principle of distribution "favours the very small holders who may get their entire holdings irrigated even during water scarcity" (1991, 105). The important point, however, is that the rules concerning how scarce and valuable water is to be distributing, who will distribute the water, and how the distributors will be paid and monitored, have been devised and implemented by the farmers themselves. So instead of facing the tragedies faced by the fishers of Brixham Harbor and the power companies using The Geysers, the Kandadevi villagers have devised rules that help to avoid these problems.

Conditions Leading to a CPR Dilemma

This example illustrates that not all CPRs are tragedies. To distinguish among those CPRs that are problematic and may involve strong incentives toward a tragic dilemma and those that are not problematic, we need- to introduce two conditions that may apply to CPR situations. These are: (1) Suboptimal Outcomes and (2) Constitutionally Feasible Alternatives.

> Condition 1: Suboptimal Outcomes
>
> The strategies of the appropriators, given a particular configuration of the physical system, technology, rules, market conditions, and attributes of the appropriators, lead to suboptimal outcomes from the perspective of the appropriators.
>
> Condition 2: 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 that are individually advantageous to all appropriators or potential appropriators.[2]

Conditions 1 and 2 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.

Are All CPR Problems the Same?

Analysts frequently presume that most CPR situations are 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). This presumption leads to the error of concluding that whenever multiple appropriators withdraw subtractable units from a CPR, suboptimal outcomes will occur.[3] There are many resources that meet the definition of a CPR that do not meet Conditions 1 and 2. In some CPRs, the quantity demanded of the resource unit is not high enough to induce appropriators to pursue individual strategies that produce suboptimal outcomes. Such situations are not problematic, even though they might become so if the demand for the resource unit were to increase or appropriation costs were to decrease.

In other CPRs, the quantity demanded of the resource unit is sufficiently large that appropriators are motivated to pursue individual strategies that produce suboptimal outcomes unless they adopt coordinated strategies. A coordinated strategy is defined as a feasible strategy adopted by appropriators regarding: (a) how much, when, where, and with what technology to withdraw resource units and (b) how much and/or when to invest in supply or maintenance inputs. Two types of coordinated strategies may occur.

One type of coordinated strategy is the result of an evolutionary or learning process where appropriators eventually reach and maintain a set of individual strategies that increase joint (and individual) payoffs relative to problematic outcomes. 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). This is the solution adopted by the Kandadevi villagers to avoid extreme conflict over who received irrigation water when it was scarce. We will refer to a resolved CPR dilemma as a CPR that has successfully overcome Condition 1. It is, of course, possible for a resolved CPR dilemma to unravel due to changes in exogenous variables.

When analysts presume that all CPR situations are CPR dilemmas and must have a solution imposed by external actors, they overgeneralize. Nonproblematic CPRs and resolved CPRs are included as well as CPR dilemmas in the sweep of their policy recommendations. If these recommendations are accepted, some CPR situations are "reformed" when there is no logical need for "reform." Resolved CPR dilemmas may unravel when externally imposed solutions do not take into account prior solutions that have evolved or been designed by the appropriators themselves. In either case, costly policies are pursued that will not accomplish their objective.

For example, the fishers of Valenca, Brazil had initially faced a number of problems related to the diverse technologies they used to appropriate fish from an adjacent estuary (Cordell 1972). Gear was easily entangled and destroyed, and many fights erupted among the fishers. Fishers also fought over the choicest fishing spots (Cordell 1972, 105). The fishers gradually developed a number of rules to: (1) divide the estuary among different technologies to reduce the interference of one fishers equipment upon others, and (2) allocate fishing spots using lotteries and announcement rules so that fishing spots were assigned to particular fishers for a day at a time. In an attempt to modernize the fishery, the Brazilian government encouraged new fishers to enter the fishery. The government made low cost loans available for purchasing nylon nets to those who could show sufficient collateral to obtain the loans. Wealthy individuals living nearby purchased nets and hired men, who had no prior knowledge of fishing or the local rules, to fish with the newly acquired nets. The newcomers invaded the fishery and violent conflict erupted. The old rules were abandoned as all fishers fought for any fishing spot they could hold through physical prowess. The fishery was soon overharvested and abandoned (Cordell 1978).[4]

A further problem arises in the choice of models used to devise solutions to CPR dilemmas. For example, it is common to find policy analysis based on the presumption that the game of "Prisoner's Dilemma" adequately portrays the decision environment. As we show later in this book, subproblems within CPR dilemmas can be represented by numerous game structures beyond that of Prisoners' Dilemma. 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 vary significantly. It is an important empirical question whether strategy spaces similar in normal form, but different in extensive form, will lead to parallel observations of actual choices.[5]

Thus, there are both theoretical and policy problems with the current understanding of the behavior in CPRs. Environments that share some but not all underlying similarities are treated as if they were completely alike. Environments that are resolved CPR dilemmas are incorrectly targeted for policy reforms. Environments that share both of the conditions needed for a CPR dilemma are inappropriately represented by a single theoretical structure. It is to this latter problem that we now turn.

Classifying First Level CPR Dilemmas: Appropriation and Provision

While CPR dilemmas share much in common, the analytical problems that appropriators face in one CPR environment may vary markedly from those faced by other appropriators using other resources. The task of developing a set of rules that assigns fishers to a set of fishing spots with differential returns is different from designing a set of rules to induce labor contributions by irrigators to maintain a irrigation channel. The problems that appropriators face can be usefully clustered into two broad types: appropriation and provision.

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 efficient and equitable manner. 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 the resource. In other words, in appropriation problems, we focus attention on the flow aspect of the CPR. In provision problems, we concentrate on the stock aspect of the CPR. Clearly, within each of these two broad classes of problems, there exist a set of complex subproblems. We have found this broad classification scheme to be a useful heuristic for a broad, first-cut, classification of CPR problems.

Appropriation Problems

Solving appropriation problems focuses on the allocation of the 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 flow, (2) the timing and location of appropriation, and (3) the appropriation technologies adopted. The terms "suboptimal allocation," "assignment problems," and "technological externalities" are regularly used in the economics literature to differentiate these problems.

Appropriation problems can be conceptualized as either one-shot static situations or as iterated, time-independent situations. Thus, this classification scheme separates appropriation problems from alternative forms of dilemmas that 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.

Suboptimal Allocation

The most basic appropriation problem is suboptimal allocation of inputs in the appropriation process. An allocation is optimal when the marginal return from appropriation equals the marginal cost of appropriation for the last unit of the resource appropriated. An allocation is suboptimal when this condition is not met. The simplest model leading to a suboptimal allocation assumes identical appropriators who have unrestricted access to the CPR, resource units distributed homogeneously across space, and a single technology available to all appropriators. Suppose that appropriators continue to appropriate from the resource to the point where the average return from appropriation equals the marginal cost of appropriation. Since the average return is greater than the marginal return, they will overappropriate from the resource. In other words, treat the marginal cost of an input used in the appropriation process as a measure of the value society places on that input. If inputs are used in the appropriation process at a level such that the marginal return is less than the marginal cost, this implies that a reallocation of this input to some alternative use would be efficiency improving from societies point of view. The reason appropriators employ inputs at this inefficient level is that it is only inefficient from the point of view of the group. The economic concept of externality is useful to clarify this point. As a single user appropriates from the resource, the impact is felt by all appropriators. The standard resource model assumes that increasing levels of appropriation reduce the average return to all inputs. A single appropriator is assumed to consider the impact of increased appropriation only on his own return from appropriating. The negative impact of his appropriation on others' return is ignored. This reasoning leads to the prediction that myopic appropriators will over appropriate from the perspective of the group. As a result, there will be an over-investment of resources into the appropriation process. Net yield to appropriators from the resource will be driven below optimal levels.[6]

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" that may vary dramatically in terms of their yields. Farmers who take water from a location on an irrigation canal near the head of the system obtain much more water for their effort than farmers who take water from a "tail—end" position.

Assignment problems occur where multiple appropriators withdraw resource units from CPRs such as inshore fisheries, irrigation systems, grazing, and communal forests. In some instances, however, a wide diversity of local rules are used to give a clear order to how allocation activities are to be organized so that assignment problems are solved and conflict is eliminated or reduced. Such rules may go unrecognized since they are frequently embedded in what outsiders think of as quaint customs. Messerschmidt (1986, 463) describes one irrigation system where the potential conflict between head-end and tail-end irrigators was solved by reversing the order by which fields were irrigated for the two major crops grown during the year:

> 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: <u>kar vaalaa, nhaa mhalaa,</u> meaning 'barley from the top, buckwheat from the bottom'.

A rhyme such as this is one means that nonliterate peoples pass their rules on from one generation to another. The rules are never written down. Outsiders have no idea—unless they ask quite specific questions—the ordering principles that the appropriators use to organize withdrawal activities.

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 operate efficiently, they need to travel over a large domain. Fixed nets operating in the same territory increase the operating costs for both trawlers and fixed net users. Similarly, if one group of fishers use dynamite in their fishing efforts, the costs for other fishers rise as a result of this production technology. Many fishing communities have established extensive rules allocating fishing space to alternative technologies at different seasons to reduce the external costs. A well-documented case of allocation rules designed to cope with technological externalities is the fishing village of Fermeuse, Newfoundland (Martin 1979).

The linkages among appropriation problems are illustrated in Figure 1.1. Suboptimal allocation is the underlying behavioral dilemma. The form of suboptimal allocation varies within specific CPR environments as variables such as spatial heterogeneity or technological heterogeneity change.

[Figure 1.1 about here]

Provision Problems

Analyses of provision problems begin at the level of optimal size and productive nature of the resource 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 CPR which alters the productive capacity of the resource, demand side provision. Depending on the specific characteristics of the dilemma, provision problems may be 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 so that the CPR is able to maintain itself. In the case of a CPR dilemma, this condition is frequently 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 dependent provision problems can be arrayed as in Figure 1.2.

[Figure 1.2 about here]

Supply-Side

A classic supply side provision problem is that of the maintenance required to keep an irrigation system operating effectively (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 ensure 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 kept locally constructed irrigation canals in good working order.

Conceptually, the supply side CPR dilemma parallels the theoretical and empirical literature focusing on public goods provision. Similar to pure public good provision, maintenance or provision in a CPR environment may suffer from free riding because it is difficult to monitor. In general, however, a CPR resource differs from a pure public good in that its yields are characterized by subtractability in consumption. Thus, individual incentives for provision may vary dramatically between public goods and CPRs.

Demand-Side

Classic problems on the demand side involve the maximization of discounted present value of returns. When the discount rate used is greater than is socially optimal, this can lead to the extinction of biological species as a result of an appropriation rate higher than the minimal safe yield (see Clark 1976; Smith 1968).[7] Fieldwork by Blomquist (see Chapter X) describes 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, destroying the capacity of the basin to hold potable water. Since surface reservoirs are extraordinarily expensive, the provision problem facing the producers is to reduce withdrawal rates sufficiently to preserve the basin.

The Relationships between Appropriation and Provision Problems

In natural settings, individuals most frequently face combined appropriation and provision problems. Any humanly constructed CPR, such as an irrigation system, must be provided before anyone can appropriate from it. Even those CPRs provided by nature, such as groundwater basins or fisheries, may involve extensive demand-side provision activities so avoid their destruction through over-use. Provision activities affect the amount of resources that are available for appropriation. Thus, the severity of the appropriation problem is affected by how well the provision problem is solved.

Analytically, however, it is useful to separate the problems to clarify what is involved in reducing the severity of each type of problem. Appropriation problems are an easier class to analyze. Also, there are many problems that appropriators face in CPRs that are strictly appropriation problems. Consequently, in our theoretical and experimental chapters we will address these problems independently so as to gain better understanding of the types of actions associated with variously structured appropriation and provision problems. When problems are complexly inter-related, it is difficult to get any firm analytical understanding of them without focusing on sub-parts of a complexly related series of problems. We do recognize, however, that provision and appropriation problems are linked together in natural settings and this linkage is addressed in the chapters reporting on research conducted in field settings and again in the last section.

Higher Level CPR Dilemmas: Monitoring and Sanctioning

A group of appropriators facing a CPR dilemma who decide to adopt new rules that change the structure of that situation, would then face a series of

(1) impose solutions on the individuals involved—-no presumption that individuals can affect the structure of the situation in which they find themselves.

(2) impose highly simplified solutions without much attention to the problems of (a) the specific physical environments involved, (b) the type of rules that have been developed already by participants (if any) and/or previous experience of appropriators with different type of rules and their capacities to make effective use of rules of one kind versus another, (c) the problems of monitoring and enforcement that may be involved.

(3) to create authorities to regulate rather than forums where the participants have an opportunity to craft their own rules and participate in the governance of a resource.

The Plan for This Book

[We will present an overview of the book in this concluding section of Chapter 1.]

Figure 1.1. A Framework for Appropriation Problems

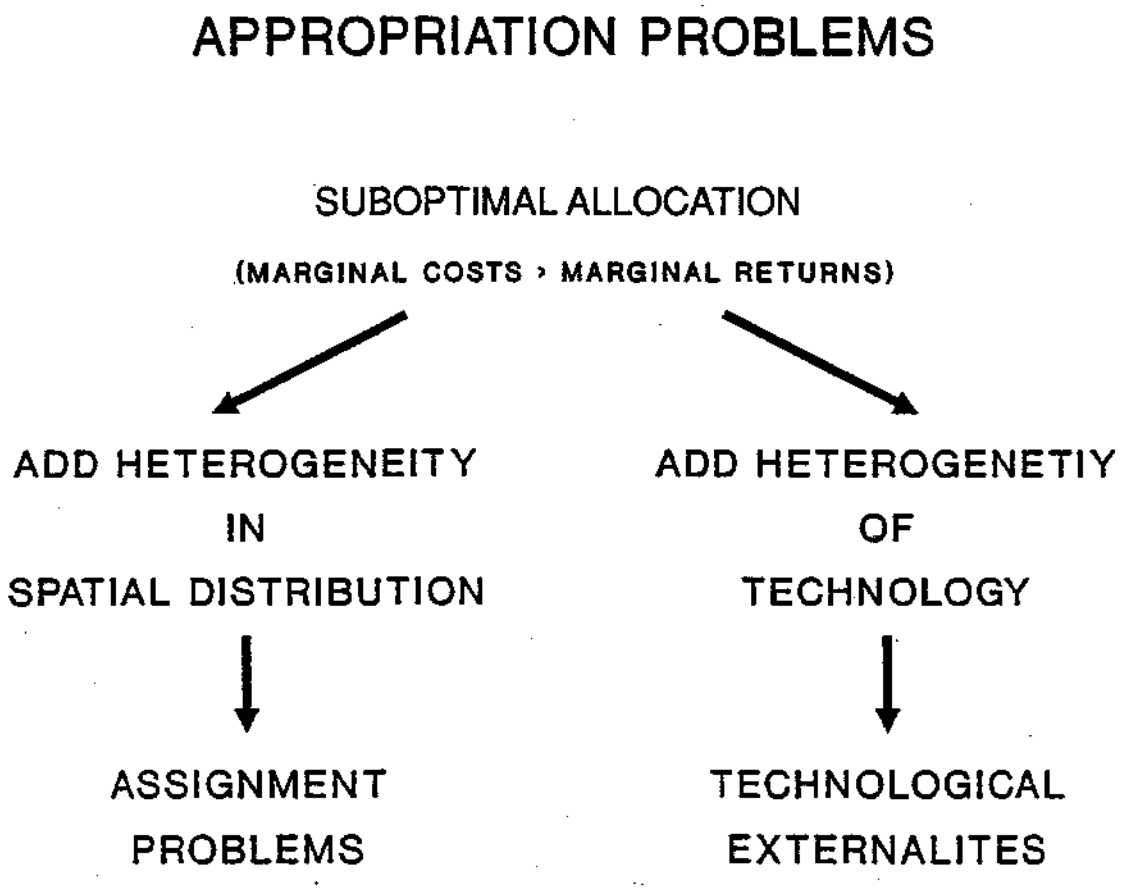
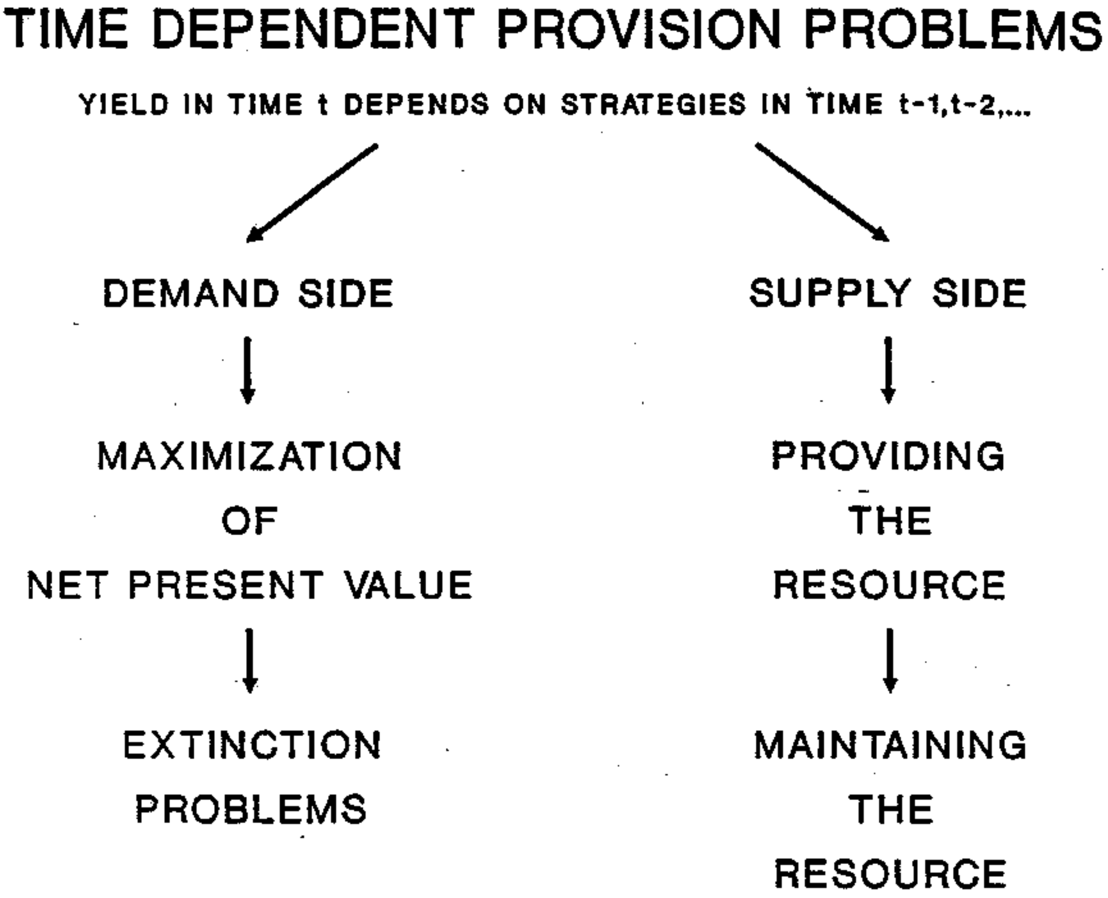


Figure 1.2. A Framework for Provision Problems



Notes to Chapter 1

1. We follow Plott and Meyer (1975) in calling the process of withdrawing units "appropriation" and thus the term "appropriator" for all those who withdraw units including groundwater pumpers, irrigators, fishers, hunters, herders, computer users, etc.

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

3. Several recent books contain a wide diversity of cases that illustrate that many CPR situations with multiple appropriators are not open access nor are they CPR dilemmas (see Berkes 1989; Blaikie and Brookfield 1987; Marshak 1987; McCay and Acheson 1987; National Research Council 1986; Pinkerton 1989; Sengupta 1991; and V. Ostrom, Feeny, and Picht 1988).

4. Mathews (1988) and Matthews and Phyne (1988) document similar problems in Newfoundland, Canada.

5. 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. See also Harsanyi and Selten (1988, ch. 2).

6. 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.

7. The demand side provision problem is conceptually akin to 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.

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Chapter 2

Institutional Analysis and Common-Pool Resources

The substantive questions of this book relate to how and when individuals using common-pool resources (CPRs) establish enforceable rules that enable them to use these resources relatively efficiently. The theoretical questions of this book relate to how rules are linked to strategic behavior within well-structured, repetitive situations that can be analyzed as games. Thus, CPR problems are of major interest to us because they (1) are so prevalent in the world and represent such important problems, and (2) provide a well-focused set of problems to apply the evolving insights and methods of a framework for analyzing institutional arrangements. Chapter 1 explored the first reason. This chapter focuses on the second.

The Institutional Analysis and Development Framework

Institutional analysis is carried out at three levels:

1. The development of a general framework for identifying the broad components and their relationships in well specified institutional contexts. Such frameworks help to organize diagnostic and prescriptive inquiry.
2. The development and use of more formal theories that make general assumptions about the components of a decision environment. Institutional analysis at this level addresses a series of questions regarding the relationship between components of the decision environment. The theoretical analysis may focus on some subset of the broad framework, making simplifying assumptions that are necessary for an analyst to diagnose a problem, explain its sources, and formulate solutions. Several competing theories may be used to analyze a given framework.
3. The development and use of specific models that formalize specific components of the decision environment to deduce expected outcomes.

> At this level, parametric values are assumed and the consequences of changing such parameterizations are addressed. Several competing theories may be used to analyze a given model.

For policy makers and scholars interested in issues related to how rules enable users of CPRs to solve appropriation and provision problems, a framework helps to organize diagnostic, analytical, and prescriptive capabilities. It also aids in the accumulation of knowledge from empirical studies conducted in both field and experimental settings and in the assessment of past efforts at reforms.

Markets, hierarchies, and collective actions situations are frequently presented as fundamentally different "pure types" of situations. Not only are these situations perceived to be different, but each is presumed to require its own explanatory theory. Scholars who attempt to explain behavior within markets may rely totally on neoclassical micro-economic theory. Scholars who attempt to explain behavior within hierarchies may rely totally on political and sociological theory. And, scholars who attempt to explain behavior in a collective action environment may rely totally on noncooperative game theory. Such a view precludes a more general explanatory framework and closely related theories that help analysts to make cross institutional comparisons and evaluations. This is particularly relevant now that so much attention is being paid to the enhancement and reform of various kinds of institutions—especially those related to the use of the environment. One needs a common framework and family of theories in order to address questions of reform and transition.

Is there a common set of variables that underlie all types of institutional arrangements? If such a common set of variables exists, then many differences in surface reality can be expected to result from the way these variables are assigned different values and are combined with or interact with one another. Such a set of variables would provide the foundation for a general framework for comparing institutional arrangements across diverse institutional contexts. Such a framework would identify the structural variables present in all institutional arrangements, but whose extensive form or parametric values differ from one type of institutional arrangement to another. The framework called Institutional Analysis and Development (IAD) incorporates the efforts of many researchers to identify such a set of variables.[1]

The first step in an institutional analysis using the IAD approach is the identification of a conceptual unit—called an *action arena*—that can be utilized to analyze, predict, and explain behavior within institutional arrangements. Action arenas include a model or models of an *action situation* and a model or models of the actors in that situation. An action situation can be characterized using seven clusters of variables: (1) positions, (2) participants, (3) actions, (4) potential outcomes, (5) a function that maps actions into realized outcomes, (6) information, and (7) the costs and benefits assigned to actions and outcomes. The model of the- actor includes assumptions about four clusters of variables: (1) the resources that an actor brings to a situation, (2) the valuation actors assign to states of the world and to actions, (3) the way actors acquire, process, retain, and use knowledge contingencies and information, and (4) the processes actors use for selection of particular courses of action.

An action arena refers to the social space where individuals interact, exchange goods and services, solve problems, engage in appropriation and provision activities, or fight (among the many things that individuals do in action arenas). In field settings, it is hard to tell where one action situation starts and another leaves off. Life continues in what appears to be a seamless web as fishers move from home to a harbor to a nearby fishing grounds and then to a market where the day's haul is sold. Further, within arenas, choices of actions *within* a set of rules as contrasted to choices *among* future rules are frequently made without recognizing that the level of action has shifted. So, when the owner of a fishing boat says to a member of the crew "How about changing the way we do X," and the two discuss various options and jointly agree upon a better way, they have shifted from taking actions within previously established rules to making decisions about the rules structuring future actions. Or, using IAD language, they have shifted to a collective-choice level.

Thus, two additional steps can be taken after an effort is made to understand the initial structure of an action arena. One step digs deeper and inquires into the factors which themselves affect the structure of an action arena. From this vantage point the action arena is viewed as an intermediate conceptual unit. The values of the variables in an action arena are now viewed as dependent upon other factors. These factors include three clusters of variables: (1) the rules used by participants to order their relationships, (2) the attributes of states of the world which are acted upon in these arenas, and (3) the structure of the more general community within which any particular arena is placed (see Kiser and E. Ostrom 1982). The second step that may be taken in any particular institutional analysis -is to move outward from action arenas and their underlying physical, cultural, and rule structures to an analysis of the complex structures that link sink sequential and simultaneous action arenas to one another. Prior to a discussion of these more complex issues, however, let us first focus on the common set of elements that can be used to construct a framework of a market, a hierarchy, or a collective action problem. Figure 2.1 illustrates this process. In our discussion of these elements, we will start with the proximate structure—the action arena—used to predict results. Then, we will focus on the deeper structure of the situation whereby rules, states of the world, and attributes of a community affect the structure of an action arena. Finally, we will discuss linked action situations and tiered levels of analysis.

[Figure 2.1 about here]

Diagnosis and Explanation within an Action Arena

The term action arena refers to a complex conceptual unit containing one set of variables called an action situation and a second set of variables called an actor. One needs both components—the situation and the actors in the situation—to diagnose, explain, and predict actions and results.

The Action Situation

The term action situation is used here to refer to an analytic concept that enables an analyst to isolate the immediate structure affecting a process of interest, for the purpose of explaining regularities in human actions and results. A common set of variables used to describe the structure of action situation include:

(1) The set of *positions* to be held by participants.

Ex: right holder, first-mover, monitor, elected representative, judge, etc.

(2) The set of *participants* (including a random actor where relevant) in each position.

Ex: The number and attributes of fishers currently fishing in a particular fishing grounds or farmers using an irrigation system.

(3) The set of *actions* that participants in positions can take at different nodes in a decision tree.

Ex: Decide to fish or not to fish during time period Tl; go to fishing spot A or B; fight or not fight for spot if someone else is there.

(4) The set of *potential outcomes* that participants jointly affect through their actions.

Ex: The quantity of fish caught in all available fishing spots depending on whether other fisher are there and whether one has to fight for a spot.

(5) The set of *functions* that map participant and random actions at decision nodes into intermediate or final outcomes.

Ex: The production function that maps individual and group decisions regarding fishing or irrigating into realized outcomes.

(6) The amount of *information* available at a decision node.

Ex: The amount of information any actor has about all aspects of the action situation, the values attached to outcomes by others and the moves taken by other players.

(7) The set of *payoffs* that assign benefits and costs to actions and outcomes.

Ex: The price offered to the fisher for fish brought to market, the price of rice offer to the irrigator for crops brought to market, the fines attached to illegal actions, taxes paid on various activities, etc.

These seven variables plus a model of the actor must be explicitly stated (or are implicitly assumed) in order to construct a model of an interdependent situation. In Chapter 3, we provide several examples of how these elements are used to construct different types of CPR games. We consider these to be a universal set of necessary variables for the construction of theories and models of settings where realized outcomes are dependent on the acts of more than a single individual. This is a minimal set in that it is not possible to generate a prediction about behavior in an interdependent situation without having explicitly or implicitly specified something about each of these variables and related them together into a coherent structure. We call the analytical entity created when these variables are specified an action situation.

A standard mathematical structure for representing an action situation is a game in extensive form (Selten 1975; Shubik 1982). The decision environment faced by participants in a well constructed laboratory experiment is also a means of representing an action situation. The concept of an action situation is, however, broader than any of the particular theoretical formalisms that may be used in analysis. Using these seven variables, a simple working model of any particular type of situation whether a CPR, a committee, a market, or a hierarchy can be constructed.[2] A change in any of these variables produces a different action situation and may lead to very different outcomes. More complex models of CPBs, committees, markets, or other interdependent situations are constructed by adding to the complexity of the variables used in the simple working model.[3]

Models of an Actor

In addition to the variables of an action situation, an analyst must also utilize a model of an actor, which specifies how individuals process information, how they assign values to actions and outcomes, how they select an action, and what resources they have available. The actor in a situation can be thought of as a single individual or as a group functioning as a corporate actor. In order to derive inferences about the likely behavior of each actor in a situation (and, thus, about the pattern of joint results that may be produced), the analyst must make assumptions about what outcomes participants value and how such values are conceived, what resources and information they have, their information processing capabilities, and the internal mechanisms they use to decide upon strategies. The term "action" refers to those human behaviors for which the acting individual attaches a subjective and instrumental meaning. The model of the individual is the animating force that allows the analyst to generate predictions about likely outcomes given the structure of the situation (Popper 1967).

Classical game theory (e.g., von Neumann and Morgenstern 1944, ch. 2) assumes that players are completely rational, with unlimited computational powers. These extreme assumptions apply, whether one is studying cooperative or noncooperative games, and regardless of the form of the game. Similar assumptions are made in neoclassical microeconomic theory. In part, because of the extremity of these assumptions, powerful mathematical results can be deduced from them. For some field settings, these theories are highly successful explanatory and diagnostic tools. For those settings, using these assumptions about individual choice turns out to be a very useful way of applying institutional analysis. Unfortunately, empirical results do not always accord with mathematical deductions. For instance, one of the hallmarks of the rationality concept in game theory is backward induction (Harsanyi and Selten 1987, ch. 2). In behavioral laboratories, however, players of experimental games rarely give evidence of performing backward induction (cite APSA). This and other lapses of rationality have led game theorists to relax the classical assumption of complete rationality and unlimited computational powers in the concept of bounded rationality (Selten 1991). We explore this relaxation of complete rationality in the final chapter.

When a theorist analyzes an action arena, the model of the situation and the model of the actor are assumed as given (see examples in Chapter 3). At this level of analysis, the task of the analyst is viewed as one of predicting the type of behavior and results, given this structure. Questions concerning the presence or absence of retentive, attractive, and/or stable equilibria and evaluations of the efficiency and equity of these results are pursued at this level. The question being investigated is: Given the analytical structure assumed, how does this situation work to produce outcomes?

Factors Affecting Action Arenas

Underlying the way analysts model action arenas are explicit or implicit assumptions about the *rules* individuals use or face to order their relationships, about attributes of *states of the world* and their transformations, and about the *nature of the community* within which the arena occurs. In Chapter 4 we address the interrelationship of these components. Below, we lay the foundation for clarifying the meaning and attributes of each of these factors.

The Meaning of Rules

Rules, as we use the term, are potentially linguistic entities that refer to prescriptions about what actions (or states of the world) are *required, prohibited*, or *permitted.* All rules are the result of implicit or explicit efforts to achieve order and predictability among humans by creating classes of persons (positions) who are then required, permitted, or forbidden to take classes of actions in relation to required, permitted, or forbidden states of the world.

Rules are potentially linguistic entities that are contextual, prescriptive, and followable (Shimanoff 1980). They are contextual in the sense that they apply to a general set of action arenas but do not apply everywhere. The rules of chess apply *only* to situations in which participants wish to play chess, but they apply in every instance in which individuals want to play chess• The game of chess provides the context for the application of its rules. Rules are prescriptive in the sense that "those who are knowledgeable of a rule also know that they can be held accountable if they break it" (Shimanoff 1980, 41). Rules provide information about the actions an actor **"must"** perform (obligation)*,* "must not" perform (prohibition)*,* or may" perform (permission) if they are to avoid the possibility of sanctions being imposed. Rules are fallowable in the sense that it is possible for actors to perform obligatory*,* prohibited*,* or permitted actions as well as it is possible for them *not* to perform these actions. In other words*,* it is physically possible for actors to follow or not to follow a rule. This distinguishes actions that are explained by reference to rules, from behavior that is explained by scientific regularities.

To be concerned with the relationship between rules and games*,* one needs to investigate the origin of such rules. In totalitarian governance systems, a central government attempts to impose rules on most action situations occurring within its domain. It attempts to be the source of all rules and their enforcement and invests heavily in police and organized terror mechanisms in this **effort.** In totalitarian governance systems, action systems that are organized in the open rely primarily on the rules that come down from central authorities. Given the extreme sanctions that can be imposed. individuals interacting with strangers try to stay within the "letter of the law*' as prescribed. Behind the scenes, however, many activities are organized using rules other than those prescribed by a central regime. Government officials try to extort bribes from citizens (or businesses) who may try to evade government regulations by keeping some things hidden and paying off officials. Special accommodations are made in secret that are exactly counter to the "letter of the law," Thus, in a totalitarian regime where individuals have had an opportunity to begin to make accommodations with one another, there are many sources of the rules used in daily **life.** Some of these rules are exactly counter to the prescriptions laid down by the formal government.

In open and democratic governance systems, there are also many sources of the rules that individuals use in everyday life. It is not considered illegal or improper for individuals to self-organize themselves and craft their own rules, and enforce these rules so long as the activities involved are legal. In addition to the legislation and regulations of national governments, there are apt to be laws passed by regional, local and special governments. Within private firms and voluntary associations, individuals are authorized to adopt many different rules for who is a member of the firm or association, how profits (benefits) are to be shared, how decisions will be made. Each family constitutes its own rule-making body.

When individuals genuinely participate in the crafting of multiple layers of rules, some of that crafting will occur using pen and paper. Much will occur, however, as problem solving individuals interact trying to figure out how to do a better job in the future than they have done in the past. Colleagues in a work team are crafting their own rules when they say to one another something likes "How about if you do A in the **future,** and I will do B, and before' we ever make a decision about C again, we both discuss it and make a joint decision,, In a democratic society, problem solving individuals do this all the time. They also participate in less fluid decision-making arrangements including elections to select legislators. Elected representatives may then engage in open, good-faith attempts to solve a wide diversity of problems brought to them by their constituents. It is also possible in a governance system where individuals are elected, for patterns to emerge that are not strictly problem solving. Incentives exist to create mechanisms whereby one set of individuals dominates others.

Thus, when we do institutional analysis, we attempt first to understand the working rules that individuals are using in making decisions. Working rules are the rules in use by participants in on-going action arenas. They are the rules devised by the Kandadevi villagers for allocating water or the Valenca fishers to allocate fishing spots and gear locations. They are the set of rules to which participants would refer if asked to explain and justify their actions to fellow participants.[4] They are the rules that they expect their fellow participants to use in sanctioning them if not followed. While following a rule may become a "social habits" it is possible to make participants consciously aware of the rules they use to order their relationships. Individuals can consciously decide to adopt a different rule and change their behavior to conform to such a decision. Over time, behavior in conformance with a new rule may itself become habitual (see Shimanoff 1980; Toulmin **1974;** Harre 1974). The capacity of humans to use complex cognitive systems to order their own behavior at a relatively sub-conscious level makes it difficult for empirical researchers to ascertain what the working rules are for an on-going action arena may be.

Rule following or conforming actions are not as predictable as biological or physical behavior explained by scientific laws. All rules are formulated in human language. As such, rules share all the problems of lack of clarity, misunderstanding, and change that typifies any language-based phenomenon. Words are "symbols that name, and thus, stand for classes of- things and relationships" (V. Ostrom **1980, 312).** Words are always simpler than the phenomenon to which they refer.

The stability of rule-ordered actions is dependent upon the shared meaning assigned to words used to formulate a set of rules and how they will be enforced. If no shared meaning exists when a rule is formulated, confusion will exist about what actions are required, permitted, or forbidden. Regularities in actions cannot result if those who must repeatedly interpret the meaning of a rule within action situations arrive at multiple interpretations. Because "rules are not self-formulating, self-determining, or self-enforcing" **(ibid.)/** it is human agents who formulate **them,** who apply them in particular situations, and who attempt to enforce performance consistent with them. Even if shared meaning exists at the time of the acceptance of a rule, transformations in technology, in shared norms, and in circumstances more generally, change the events to which rules apply. "Applying language to changing configurations of development increases the ambiguities and threatens the shared criteria of choice with an erosion of their appropriate meaning" (ibid.)

What rules are important for institutional analysis? A myriad of specific rules are used in structuring complex action arenas. Scholars have been trapped into endless cataloging of rules not related to a method of classification most useful for theoretical explanations. But classification is a necessary step in developing a science. Anyone attempting to define a useful topology of rules must be concerned that the classification is more than a method for imposing superficial order onto an extremely large set of seemingly disparate rules. By asking how rules affect the structures of action situations", we can hopefully begin to develop a useful way to cluster rules that can serve as a first step in a theory about how rules relate to the structure of action situations, thereby affect the way individuals act and achieve or produce results.

Types of Rules and Rule Configurations

From sets of physically possible actions, outcomes, payoffs, decision functions, information, positions, and participants, rules may alter the feasible sets of the values of these variables. The action situation is the intersection of these feasible sets. In regard to driving a car for example, it is physically possible for a 13 year old to drive a car at 120 miles per hour on a freeway. If one were to model the action situation of a freeway in a state with well enforced traffic laws, one would posit the position of licensed drivers filled by individuals 16 and over traveling an average of 60 to 65 miles per hour (depending on the enforcement patterns of the state)• The values of the variables in the action situation are constrained by the type of physical world involved and then, further constrained by the rules in use. Most of formal analysis of a game focuses primarily on the structure of the action arenas this is the surface structure that our representations model. The rules are part of the underlying structure that shapes the representations we use. But, how do we overtly examine this part of the underlying structure? What rules should be examined when we conduct analysis at a deeper level?

We can Identify seven broad types of rules that operate configurationally to affect the structure of an action situation. In the list of rules we present here, we emphasize the working part of an action situation (game) that a particular kind of rule directly affects. These rules includes

(1) Position rules specify a set of *positions* and how many participants are to hold each position.
Ex: Farmers sharing an irrigation system frequently create positions such as member (of an irrigation association), water distributor, guard, member of a tribunal (to adjudicate disputes over water allocation), and other officers of an association.

(2) Boundary rules specify how *players* are enter or leave these positions.
Ex: An irrigation association has rules that specify how a farmer becomes a member of the association and can vote for officers of an irrigation association and the qualifications that individuals must have to be considered eligible to hold a position as an officer of the association.

(3) Authority rules specify which *set of actions* are assigned to which position (including chance) at each node of a decision tree.
Ex: If a farmer challenges the actions taken another fanner or the water distributor, the rules of an irrigation association specify what a water distributor or guard may do next.

(4) Aggregation rules specify the *decision function* to be used at a particular node, to map actions Into intermediate or final outcomes.
Ex: When a decision is made at a meeting of an irrigation association about changing association rules, the votes of each member present and voting is weighted (frequently each vote is given equal weight, but it may be weighted by the amount of land owned or other factors) and added. When fifty percent plus one of those voting (presuming a quorum) vote to alter legislation, the rules are

altered. If less than fifty percent plus one vote for the change, the rules remain unchanged.

(5) Scope rules specify the set *of outcomes* that may be affected, including whether outcomes are intermediate or final.

Ex: Rules that specify that the water stored behind a reservoir may not be released for irrigation if the level sinks below the level required for high priority power generation.

(6) Information rules specify the kind of *information* available to each position at a decision node.

Ex: Rules that specify that the financial records of an irrigation association must be available to the members at the time of the annual meeting.

(7) Payoff rules specify how *benefits and costs* are required, permitted, or forbidden in relation to players, based on the- full set of actions taken and outcomes reached.

Ex: Rules that specify whether a farmer may sell any of the water received from an irrigation system, what crops may be grown, how guards are to be paid, and what labor obligations may be involved to keep the system maintained.

Given the wide diversity of rules that are found in everyday life, they could be classified in many ways. The method used here has several advantages. First, rules are tied directly to the variables of an analytical entity familiar to all formal theorists. Second, one has a heuristic for identifying the rules affecting the structure of that situation. Finally, one has a conceptual tool for inquiry about how rules affect a given situation. For each variable identified in the action situation, the theorist interested in rules needs to ask what rules produced the variable as specified in the situation. For example, in regard to the number of participants, the rule analyst would be led to asks Why are there N participants? How did they enter? Under what conditions can they leave? Are there costs, incentives, or penalties associated with entering or exiting? Are some participants forced into entry because of their residence or occupation?

In regard to the actions that can be taken, the rule analyst would asks Why these actions rather than others? Are all participants in positions assigned the same action set? Or, is some convener, or other position, assigned an action set containing options not available to the remaining participants? Are sets of actions time or path dependent?

In regard to the outcomes that can be affected, the rule analyst would asks Why these outcomes rather than others? Are the participants all principals who can affect any state variable they are defined to own? Or, are the participants fiduciaries who are authorized to affect particular state variables within specified ranges but not beyond? Similar questions can be asked about each variable overtly placed in a model of an action situation.

Answers to these sets of questions can then be formalized as a set of relations that, combined with the structure of a physical world and the type of community involved, produce the particular values of the variables of the situation. As we show in Chapter 4, there is not a unique set of relations that produce any particular model of a situation. Given the frequency of situations with the structure of a Prisoners' Dilemma, one can expect that multiple sets of rules produce action situations with the same structure. This is not problematic when one focuses exclusively on predicting behavior within the situation. It poses a serious problem when the question is how to change that structure. To change a situation, one must know which set of rules produce the situation.

Besides providing a general heuristic for identifying the relevant rules that affect the structure of a situation, a second advantage of examining the rules that directly affect the seven components of an action situation leads to a relatively natural classification system for sets of rules. Classifying rules by what they affect enables us to identify rules that all directly affect the same working part of the situation. This should enhance our capabilities for developing a formal language for representing rules themselves. Specific rules used in everyday life are named in a nontheoretical manner—-frequently referring to the number of the rule in some written rule book or piece of legislation. Theorists studying rules tend to name the rule they are examining for some feature related to the particular type of situation in which the rule occurs. For systematic accumulation to occur, rules that are structurally the same rule but called by different everyday names, need to be identified as the same rule.

States of *the World and Their Transformation*

While a rule configuration affects all of the elements of an action situation, some of the variables of an action situation are also affected by attributes" of the states of the world and their transformation. What actions are physically possible, what outcomes can be produced, how actions are linked to outcomes, and what is contained in the actors' information sets are affected by the world being acted upon in a situation. The -same set of rules may yield entirely different types of action situations depending upon the types of events in the world being acted upon by participants.

The attributes of states of the world and their transformation are explicitly examined when the analyst self-consciously asks a series of questions about how the world being acted upon in a situation affects the outcome, action sets, action-outcome linkages, and information sets in that situation. The relative importance of the rule configuration and states of the world in structuring an action situation varies dramatically across different types of action situations. The rule configuration almost totally constitutes some games, like chess, where physical attributes are relatively unimportant. There is little about the size of a chess board or the shape of the pieces that contributes to the structure of a chess game. On the other hand, imagine, for a moment, switching the balls used in American and European football. The strategies available to players in these two games, and many other sports, are strongly affected by the physical attributes of the balls used, the size of the field, and the type of equipment.

The relative importance of working rules to attributes of the world also varies dramatically within action situations considered to be part of the public sector. A legislature is closer in many respects to chess than to football. Rules define and constrain voting behavior inside a legislature more than attributes of the world. Voting can be accomplished by raising hands, by paper ballots, by calling for the ayes and nays, by marching before an official counter, or by installing computer terminals for each legislator on which votes are registered. In regard, however, to organizing communication within a legislature, attributes of the world strongly affect the available options. The principle that only one person can be heard and understood at a time in any one forum strongly affects the capacity of legislators to communicate effectively with one another (see V. Ostrom 1987). The strategies available to farmers using an irrigation system are similarly strongly affected by whether the system has storage, whether the canals are gated and lined, the pattern of rainfall in the area, soil conditions, and many other aspects of the physical and biological world they face.

Attributes of a Community

A third set of variables that affect the structure of an action arena relates to the community. The attributes of a community which are important in affecting the structure of an action arena include the norms of behavior generally accepted in the community, the level of common understanding potential participants share about the structure of particular types of action arenas, the extent of homogeneity in the preferences of those living in a community, and the distributions of resources among those affected. The term "culture" is frequently applied to this bundle of variables.

Linking Action Arenas

In addition to analysis which digs deeper into the factors affecting individual action arenas, an important development in institutional analysis is the examination of linked arenas. While the concept of a "single" arena may include large numbers of participants and complex chains of action, most of social reality is composed of multiple arenas linked sequentially or simultaneously.

When individuals wish to intervene to change the structure of incentives and deterrents faced by participants in socially constructed realities to guide (or control) participants toward a different pattern of results, they do so by attempting to change the rules individuals use to order their interactions within particular types of action arenas. How rules affect behavior and results has not, however, been a question at the forefront of intellectual inquiry in political science, public administration, policy sciences, organization theory, and other disciplines that study the public sector.

Some interesting and important institutional arrangements for coordinating complex chains of actions among large numbers of actors involve multiple organizations competing with one another according to a set of rules. Markets are the most frequently studied institutional arrangements that achieve coordination by relying primarily on rule-governed competitive relationships among organizations. Rule-governed competition among two or more political parties is considered by many analysts to be an important requisite for a democratic polity. Less studied, but potentially as important means for achieving responsiveness and efficiency in producing public goods and services, are arrangements that allow rule-ordered competition among two or more potential producers of public goods and services.

Most of the efforts to analyze the effects of institutional arrangements in the public sector have focused primarily on single arenas such as elections, legislatures, administrative agencies, courts, etc. A complex series of processes must be channeled through many simultaneous and sequential action arenas, however, for citizens to receive bundles of public goods and services. Farmers who jointly use an irrigation system, for example, must organize a variety of provision activities primarily related to maintenance. If the broken sides of canals are not fixed and the canals themselves not cleaned, the amount of water that actually gets to each farmer's gate declines substantially over time. Organizing the provision side of an irrigation CPR may involve deciding upon how many days a year should be devoted to routine maintenance and how work will be allocated to individual farmers, how emergency repairs should be handled, who is responsible for repairing broken embankments caused by grazing animals, and how new control gates and regulatory devices are to be installed and paid for. Appropriation activities are closely linked to these provision activities. How much water is available for distribution is dependent upon whether a system is kept in good repair. The level of conflict over water distribution is apt to be higher on a poorly maintained system than on a better maintained system. In many places in this volume we will focus on one arena rather than the linked arenas for analytical clarity, but they are strongly linked as shown by Tang in Chapter xx.

Multiple Levels of analysis

Besides there being multiple and nested action arenas, the nesting of arenas can also be conceptualized across several levels of analysis. All rules are nested in another set of rules that define how the first- set of rules can be changed. The nesting of rules within rules at several levels is similar to the nesting of computer languages at several levels. What can be done at a higher level will depend on the capabilities and limits of the rules (or the software) at that level and at a deeper level. Whenever one addresses questions about i*nstitutional change,* as contrasted to action within institutional constraints, it is necessary to recognize the fallowings

1. Changes in the rules used to order action at one level occur within a currently "fixed™ set of rules at a deeper level.
2. Changes in deeper-level rules usually are more difficult and more costly to accomplish, thus increasing the stability of mutual expectations among individuals interacting according to a set of rules.

It is useful to distinguish three levels of rules that cumulatively affect the actions taken and outcomes obtained in any setting (Kiser and E. Ostrom 1982) (see Figure 2.2).

[Figure 2.2 about here]

(1) Operational rules directly affect day-to-day decisions made by the participants in any setting.

(2) Collective-choice rules affect operational activities and results through their effects in determining who is eligible and the specific rules to be used in changing operational rules.

(3) Constitutional-choice rules affect operational activities and their effects in determining who is eligible and the rules to be used in crafting the set of collective-choice rules that in turn affect the set of operational rules. One can think of the linkages among these rules and related level of analysis as shown in Figure 2.3.

[Figure 2.3 about here]

At each level of analysis there may be one or more arenas in which the types of decision made at that level will occur. The concept of an "arena" as described above does not imply a formal setting, but can include such formal settings as Legislatures and Courts. Policy-making regarding the rules that will be used to regulate operational-level choices is usually carried out in one or more collective-choice arenas as shown in Figure 2.4.

[Figure 2.4 about here]

Historical Roots

The (IAD) approach has its roots in classic political economy (specifically the work of Hobbes, Montesquieu, Smith, Hamilton, Madison, and de Tocqueville); neoclassical microeconomic theory, institutional economics (the work of Commons and Coase); public choice theory (Buchanan and Tullock, Olson, Downs, and Riker); transaction cost economics (Williamson and North); and noncooperative game theory (Luce and Raiffa; Harsanyi and Selten; Shubik). The working parts of the IAD framework do not always overtly show in an institutional analysis. That is the case with all frameworks. Since a framework orients the analyst to ask particular questions, it is the questions that are generated by using the framework that appear in most analyses rather than the intellectual scaffolding used by the analyst to diagnose, explain and prescribe.

The IAD framework has influenced the analysis of a diversity of questions during the past several years. It has been applied to the study of metropolitan organization (V. Ostrom, Tiebout, and Warren 1961; ACIR 1988; etc.); the theory of public goods (cites)? the sustenance of rural infrastructures in developing countries (xx) ; privatization in developed and developing countries (Oakerson); to the study of macro-political systems (Yang, Kaminski, Sawyer, V. Ostrom, Toonen) and to a considerable amount of prior work on CPR problems (cites). Work has been carried on related to patterns of order in Bangladesh, Cameroon, Ghana, India, Indonesia, Ivory Coast, Liberia, Mali, Madagascar, Nepal, Nigeria, Poland, and the earlier structure of the Soviet regime.

She IAD Framework and Theoretical Analysis

The IAD framework does not limit the researcher to one specific form of theoretical analysis. Depending upon the context of the decision environment, the researcher may in fact use the framework as a foundation for investigating the predictive power of competing theories or models.

The research approach we develop in this volume explicitly combines the IAD framework with the formal theory of noncooperative games. For some CPR problems, noncooperative game theory is particularly useful and empirical evidence (at least at the aggregate level) is consistent with predictions. This is somewhat surprising given that this theory was developed primarily as a mathematical theory. As such, it relies on extreme assumptions such as complete rationality and unlimited computational capability. For the experimental settings that we describe in Chapter 9, the predictions derived from a noncooperative game-theoretic analysis of limited access CPR games, are closely approximately by empirical results. This means that in field settings where individuals with short time horizons cannot communicate, or do not trust each other, or do not have access to reliable external enforcers, these individuals will make the suboptimal decisions predicted by noncooperative game theory.

We do not find, however, that empirical evidence from other settings described in this volume is consistent with predictions derived from noncooperative, game theory as it is currently understood. In some instances, the changes needed to make game theory a better theoretical tool for the analysis CPR problems are relatively minor. As we address in Chapter 4, for example, game theorist do not distinguish between two types of constraints that affect the structure of a game; the constraints of the physical and biological world and the constraints imposed by the rules that individuals evolve or design to limit what can be done in a particular setting. Since all of the "rules of the game™ are considered to be immutable from within the game, the possibility that individuals can themselves change the rules of the game (in a time out or a different arena) cannot easily be-addressed without making the theoretical distinctions we introduce in Chapter 4.

Closely related to the lack of attention to the difference between physical and biological "rules of the game" and humanly designed "rules of the game" is how rules are enforced. A deep assumption of modern game theory is that the rules of the game are unambiguously enforced by some agency external to the game. (How and why agents are motivated to enforce rules fully and fairly cannot, therefore, be addressed as the enforcers are "outside" the game). To understand CPR environments, however, it is necessary to bring the enforcers inside the game. Further, in many CPR environments, the enforcers are not external agents but rather the same individuals who appropriate from a resource. In Chapter 3, we construct an irrigation game where we allow players in one position to decide between following or breaking the rules of the game and the players in a second position to decide between monitoring or not monitoring the behavior of the other. We thus use a contrivance that a "legal" move within the formal game is to break the rules of the game we are modeling. Without this contrivance, the issue of rule-breaking and rule-enforcing could not be addressed by a noncooperative, game-theoretic approach. With this contrivance, we are able to show that self-monitoring can lower rule-breaking behavior but never eliminate it. In a recent paper built upon the foundations summarized in Chapter 3, Weissing and S. Ostrom (1991) have shown that external agents cannot fully eliminate rule-breaking behavior either.

We find modern game theory to be a powerful and useful tool for addressing many questions of relevance for understanding behavior and outcomes within CPR situations particularly when brought within the umbrella of the IAD framework with the consequent attention paid to the difference that rules make in the structure of a game. However, as we have continued conducting empirical work on CPR situations in field and experimental settings, we have encountered ever greater problems in explaining empirical results with only modest changes in the theoretical tools we use. In the last chapter on experimental results, we will have identified a number of anomalies that we have discovered or confirmed that cannot be explained using small modifications in the theoretical tools we have inherited. These anomalies are closely related to those found in other environments that have led other scholars to challenge theories based on assumptions of complete rationality and unlimited computational capability. Thus, having reached the limits where modern game theory as currently understood provides consistent theoretical guidance, in our last chapter we explore a theory of bounded rationality that is more consistent with the types of games that individuals create when given a chance to devise their own rules.

Figure 2.1. A Framework for Institutional Analysis

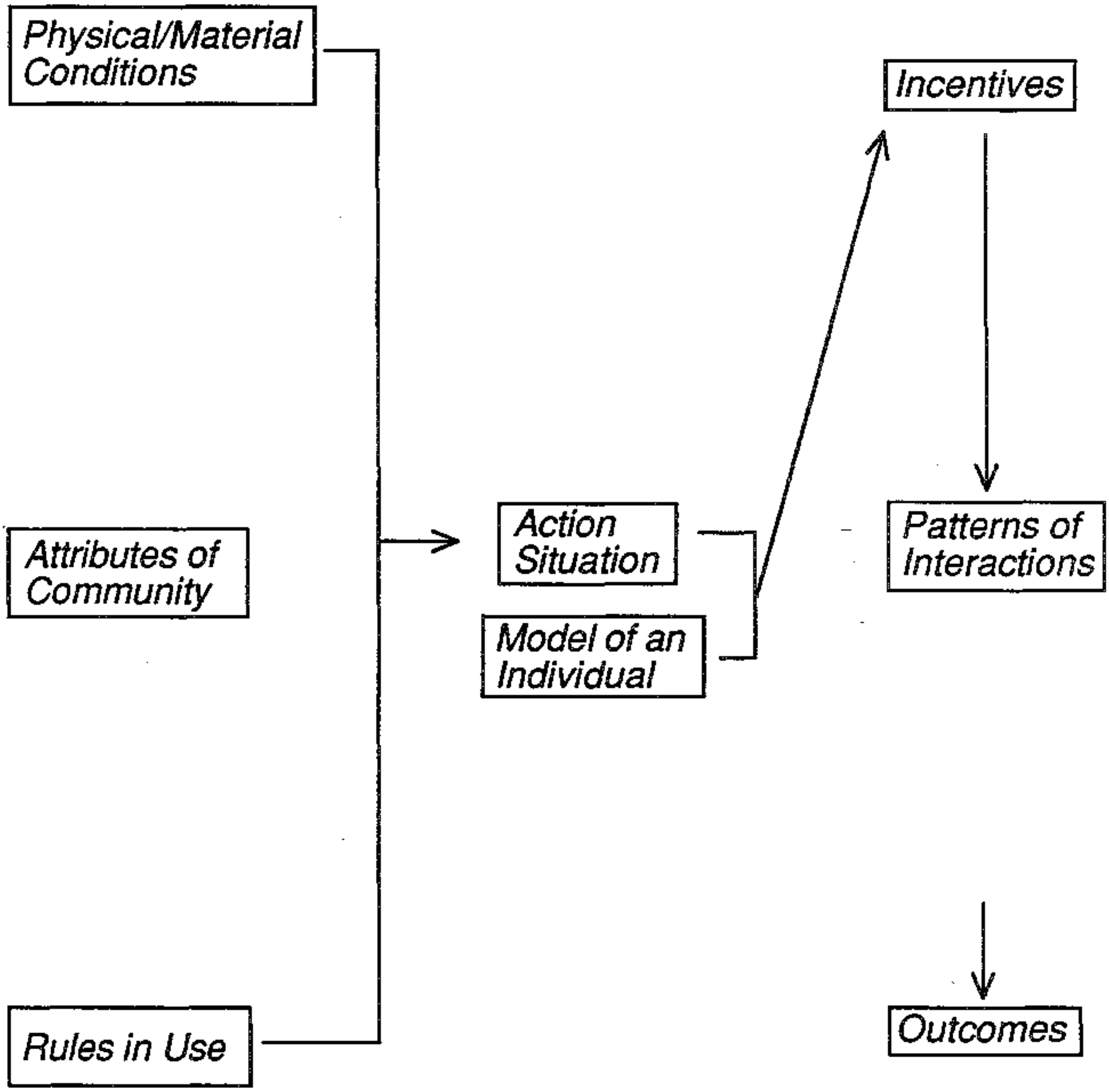
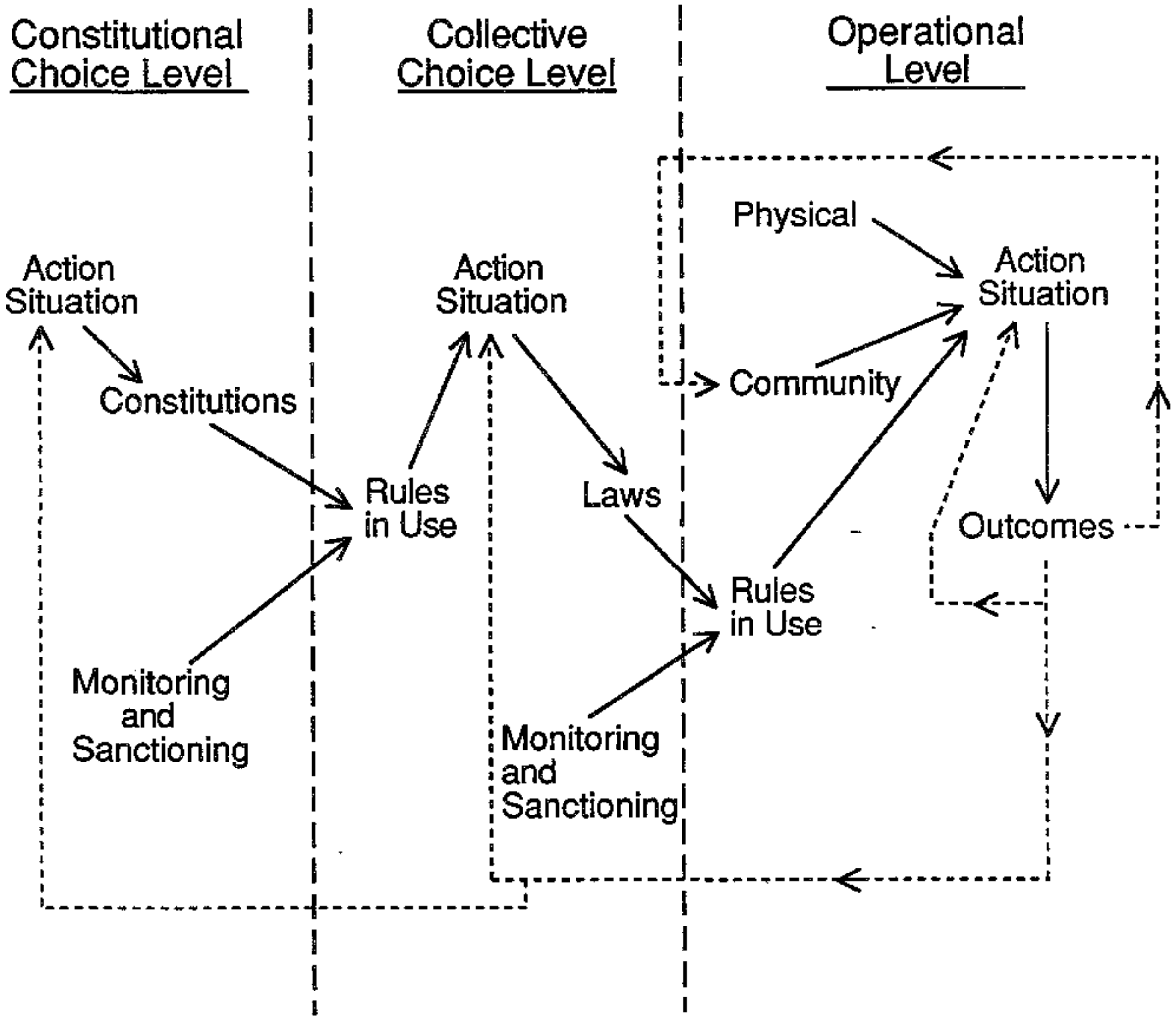


Figure 2.2. Linking Levels of Analysis



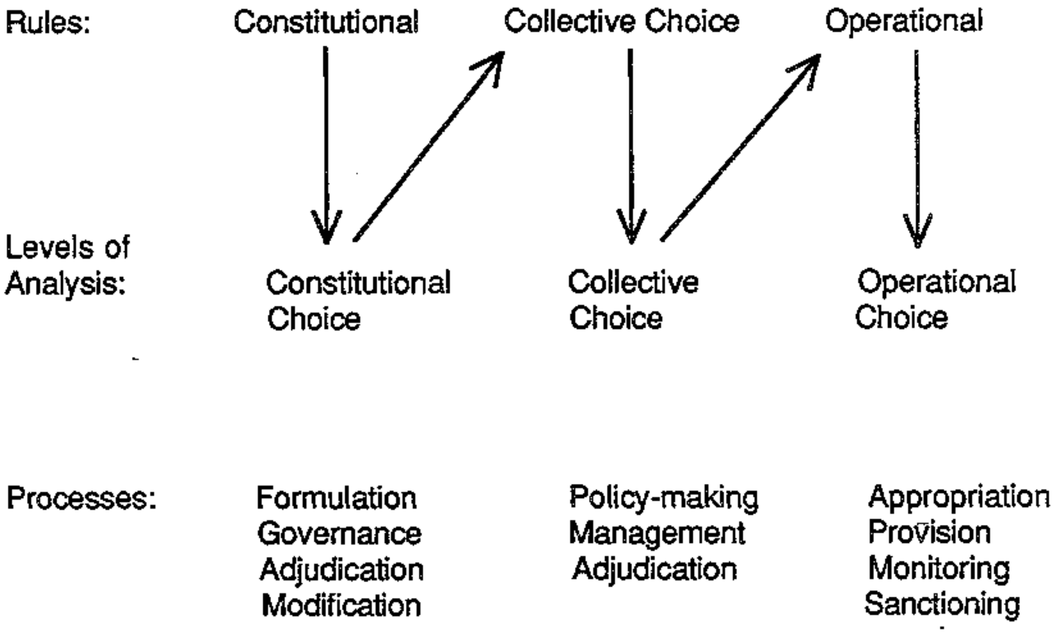
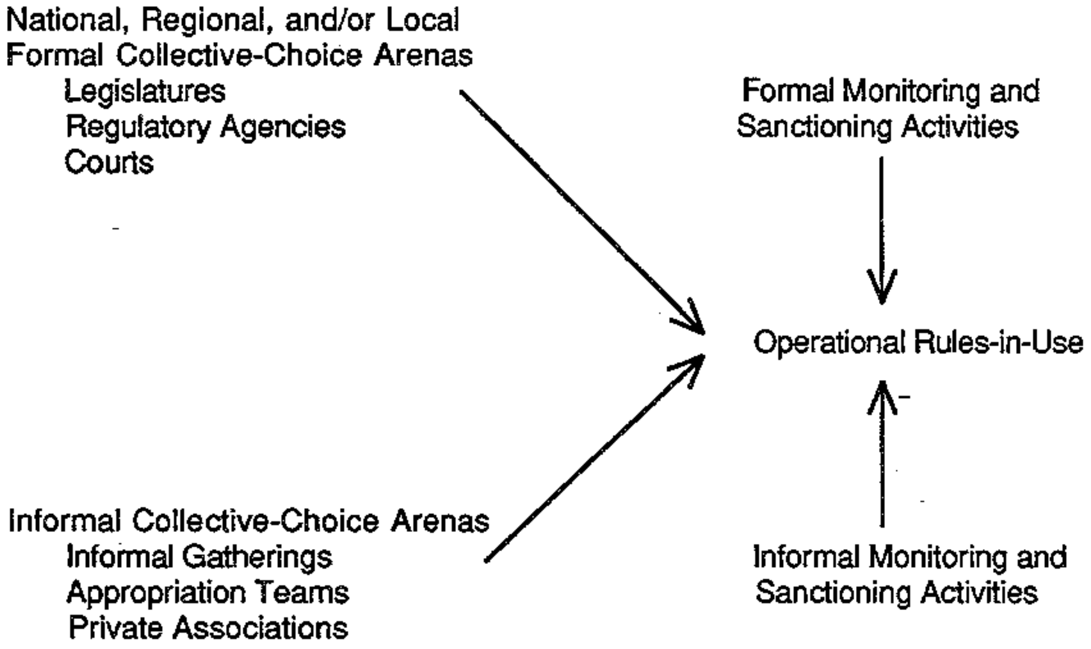


Figure 2.3. Linkages among Rules and Levels of Analysis

Figure 2.4. Relationships of Formal and Informal Collective-Choice Arenas



Notes to Chapter 2

1. Need footnote here that cites relevant literature for foundations of this work and that "development" is used to refer broadly to both the evolution of institutional arrangements over time and to the self-conscious design of institutions.

2. The simplest possible representation of a committee, for example, can be constructed using the following assumptions:

(1) One position exists; that of member.

(2) Three participants are members.

(3) The set of outcomes that can be affected by the member contains two elements, one of which is designated as the status quo,

(4) A member is assigned an action set containing two elements; (a) vote for the status quo and (b) vote for the alternative outcome.

(5) If two members vote for the alternative outcome, it is obtained; otherwise, the status quo outcome is obtained.

(6) Complete information is available about elements (1) through (5).

For this simplest possible representation of a committee, and using a well-defined model of the rational actor, we know that an equilibrium outcome exists. Unless two of the members prefer the alternative outcome to the status quo and both vote, the status quo is the equilibrium outcome. If two members do prefer and vote for the alternative outcome, it is the equilibrium outcome. The prediction of outcomes is more problematic as soon as a third outcome is added. Only when the valuation patterns of participants meet restricted conditions can an equilibrium outcome be predicted for such a simple committee situation with three members and three potential outcomes using majority rule (Arrow 1966; Plott 1967).

3. A more complex committee situation is created, for example, if a second position, that of a convener, is added to the situation, and the action set of the convener includes actions not available to the other members (e.g., Isaac and Plott 1978; Eavey and Miller 1982). See also Gardner (1983) for an

analysis of purges of recruitment to committees. Gardner's approach is very similar to the general strategy I am recommending.

4. It is not always the case, however, that participants will explain their actions to outsiders the same way they will explain them to fellow participants. Consequently, learning about the working rules used in a particular CPR may be very difficult.

CHAPTER3.DRF
October 14, 1991

Chapter 3

Games Approprxators Play

The Use of Formal Models

Even in the simplest CPR environments, the number of variables that simultaneously affect individual behavior can be relatively large. In addition, a complex interrelationship generally exists between these variables. When one tries to explain behavior in such situations,, purely verbal argumentation usually leads to at best broad insights. Further, such informal analysis can in some instances lead to conclusions which are not logically consistent. Obtaining precise qualitative or quantitative conclusions crucially depends on the exact configuration of key variables. Developing formal models where the basic variables and their configuration are well-specified is central to developing precise and detailed prediction of human behavior in such complex social systems.

In this chapter we lay the foundation for how we have applied the formal structure of game theory to the multiplicity of problems one may encounter in CPR dilemmas. Parallel to the seven components of an action situation, one can think of the basic elements of a game ass (1) a set of players, (2) a set of positions, (3) sets of actions assigned to positions at choice nodes including chance moves, (4) a decision function that maps choices into intermediate or final outcomes, {5) a set of outcomes, (6) the kind of information available at a node, and (7) payoffs based on benefits and costs of actions and outcomes. Our discussion begins with simple 2-person games to highlight the ways in which alternative CPR games may have very different strategic consequences.

The following elements specify the simplest possible game situations (1) two players, called player 1 and player 2; (2) a single position, with each player moving simultaneously exactly once; (3) a set of two actions assigned to positions, denoted strategy 1 and strategy *2;* (4) a matrix that maps choices into final outcomes, as shown in Figure 3.1; (5) a set of outcomes, here the cells of the matrix in Figure 3.1; (6) each player has available all the information contained in the matrix of figure 1 when they move; (7) the payoff parameters a,b,c, and d—where values in the upper left hand corner of each cell represent payoffs to player 1 and values in the lower right hand corner of each cell represent payoffs to player 2.

The solution concept we apply to formalizing the behavior of players in such games is that of a Nash equilibrium. In this game context, a Nash equilibrium is a pair of strategies s* = (sl*,s2*),, one for each player, with the property that player 1 has maximized his payoff by choosing s1 given his expectation of the choice of player 2, and vice versa. The player's choices represent an equilibrium (sl*,s2*) if their choices are consistent; each correctly makes his choice with the correct expectation of that of the other player. Every game in the class represented by Figure 3.1 has at least one Nash equilibrium; often there are many.

[Figure 3.1 about here]

Depending upon the exact nature of the game, Nash equilibria are described ass (1) pure or mixed and (2) symmetric or asymmetric. A pure strategy is a strategy which does not involve chance. A pure strategy equilibrium is one in which all strategic components are played with probability one. A special case of pure strategies is that referred to as a dominant strategy. In this case, each player has an incentive to play his pure strategy regardless of his expectations of the play of the other player. A mixed strategy is a strategy which involves chance. Mixed strategies require that players devise strategies where alternative decisions are made probabilistically based on a probability distribution that maximizes expected payoffs. A mixed strategy equilibrium is an equilibrium where each player plays a mixed strategy. A symmetric equilibrium is one in which every player chooses the same strategy and gets the same payoff. An asymmetric equilibrium is one in which at least two players choose different strategies and/or get different payoffs. We will see examples of each of these types of equilibria in the context of the simple 2x2 games depicted in Figure 3.1.

We begin the discussion with perhaps the most famous of all 2x2 games, the Prisoner's Dilemma (PD). Figure 3.2 shows the payoff conditions necessary for the PD games a>d, b<d, c>a. An arrow pointing down on the left means that player 1's payoff is greater by choosing row 2 if player 2 is playing column 1; an arrow pointing down on the right means that player l's payoff is greater by choosing row 2 if player 2 is playing column 2. An arrow pointing to the right on the top means that player 2's payoff is greater by choosing column 2 if player 1 is playing row 1; an arrow pointing to the right on the bottom means that" player 2's payoff is greater by choosing column if player 1 is playing row 2. This represents a natural way to detect a pure strategy equilibrium in a 2x2 games arrows pointing from both directions indicate an equilibrium. Given the inequalities in the parameter values, there is a unique pure strategy equilibrium s* = (strategy 2,strategy 2). The dilemma of course is that the equilibrium outcome is Pareto inferior to (strategy 1, strategy 1).[1] In fact, each player has a dominant strategy to play (strategy 2, strategy 2). Nash equilibrium is a rationality concept solely at the individual level, while the Pareto optimum is a rationality concept at the group level. These two rationality concepts are directly opposed in the context of PD type games.

[Figure 3.2 about here]

CPR problems have many times been equated with the structure of a PD, but this is misleading. 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 3.2. 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, 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. For example, the two games defined in the literature as the game of Chicken and the game of Assurance more closely resemble the appropriate payoff structure for many CPR related problems. If the payoffs associated with Figure 3.1 take the form (c>a, b>d, and a>d) the game that results is Chicken. Alternatively, if the payoff pattern is (a>c, d>b, a>d) the resulting game is one of Assurance. The game of Chicken represents a payoff structure and set of strategies such that individual players no longer have a dominant strategy. In fact, as will be seen in the resource assignment game to be discussed later in this chapter, this game has three equilibria. 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 a 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. In the context of the 2x2 game, the assurance game has two equilibria; one in which both players' payoffs dominate that of the other.

2x2 CPR Games

This subsection describes four games. The games illustrate game theoretic techniques in the following CPR dilemmass (1) suboptimal allocation, (2) assignment, (3) resource provision, and (4) monitoring. In each case, we demonstrate that a change in the structure of the game (for instance payoffs) can lead to equilibria that are distinct in their prediction of strategic behavior. These games illustrate the importance of carefully documenting the decision environments one might observe in field settings or In making policy decisions based on "general" models.

Suboptimal Allocation

As discussed in Chapter 1, one of the fundamental predictions for CPR dilemmas is that players will ignore the impact of their input decisions on that of others' yield from the CPR. This behavior leads to over-appropriation from the CPR. Example 1 describes how one might model this problem in the form of a 2x2 game. There are two appropriators (players). Each player has two units of a productive input, called tokens, which can be invested either in the CPR or in a safe outside opportunity. One can think of such a productive input as the time that a fisher could devote to fishing (investing in the CPR) or in working as a wage earner (a safe outside opportunity).

Suppose that:

(1) a token invested in the safe outside opportunity is worth $.50 and

(2) that the production from the CPR is governed by the quadratic production function $F(_{xi})= \Sigma_{xi}- .09(\Sigma_{xi})2$, where $_{xi}$ is the number of tokens invested in the CPR by player i.

Individual shares of this production are proportional to the number of tokens invested by a player in the CPR. The 2x2 game that results from this physical environment is portrayed in the top panel of Figure 3.3. For this token value and production function, a prisoner's dilemma results. Each player has an incentive to invest 2 tokens in the CPR. When both invest 2 tokens then overall yield to the players is suboptimal. Notice, however, that by changing the token value or the production function, games of Assurance or Chicken or even other possibilities could result. To see this, suppose that:

(1) a token invested in the outside opportunity is worth t, and

(2) the production function for the CPR is governed by the quadratic function $F(_{xi}) = \Sigma_{xi} - a(\Sigma_{xi})2$.

The general form of the payoff matrix is now given in the lower panel of Figure 3.3, with the top panel of Figure 3.3 being a special case (t=.5, a=.09). When $(1-t)/5 < a < (1-t)/6$, then a PD results. Any other parameter configuration in (a,t) space leads to a game other than a PD. Thus, a suboptimal allocation game possessing the structure of a PD is a special case of this more general class of games.

[Figure 3.3 about here]

An Assignment Problem

When players face a variety of "appropriation spots" which are differentiated in productive yield, then they are in an assignment problem. The simplest example of the assignment problem is the following game. The CPR, say a fishery, consists of two spots of known value vi, v1 > 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 3.4. The payoffs assume that two users using the same spot catch the same amount each. For vl > 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 vl = 2(v2), each user still has a dominant strategy to use spot 1. For vl < 2(v2), neither user has a dominant strategy. In this ease, there are three equilibrium points. Two of these, with one player at each spot, are 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.[2] 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 (vl, v2) are social optima. All could be improved upon by coordinated strategies of one kind or another.

[Figure 3.4 about here]

Resource Provision

Many users of a CPR are faced with the problem of providing the resource (e.g., irrigation ditches) or maintaining the resource. Such a decision problem can be modelled as one might model the provision of a pure public good. In this example, we demonstrate how such a problem (dependent upon the actual structure of the game) can be analogous to a PD game with a dominant strategy or an assurance game with multiple equilibria. Imagine two players facing the problem of providing a resource, which if provided has symmetric value to both players. Each player has one unit of input (a token) to contribute to the provision, if he desires. The token has an outside value of 1. For any token contributed by a player to provision, each player receives .75 (1.5 if both tokens are contributed). This simple payoff parameterization leads to the game matrix shown in the top panel of Figure 3.5. In this case, the provision game is a PD game with a dominant strategy to not contribute.

[Figure 3.5 about here]

Now suppose the game is changed in the following way. If only one token is contributed toward provision, there are insufficient funds for provision and the value of the contributed token is zero. This might be case in physical environments in which the good being provided is discrete (for example an incomplete bridge has no value). Now, the contributing player receives a payoff of 0 since he has foregone his outside opportunity. If both tokens are contributed, the resource is provided at a value of 1.5 to both players. This parametric change leads to the payoff structure shown in the bottom panel of Figure 3.5. Now there are two Nash equilibria (both contribute, both not contribute). In this case the equilibrium (both contribute) is payoff dominant.

Monitoring

In each of the examples given so **far,** there was a single position, player. In this example, portrayed in Figure 3.6, we consider the complication arising from two different positions, namely a player who goes first and a player who goes second.[3] The fact that there are two positions means that the game is now asymmetric, and we can expect it to have asymmetric equilibria. The positions in question are motivated by the physical reality of irrigation systems, where players at the head of the system have access to the flow before players at the tail. Thus, strategies available to player 1, the player who goes first, are to take more water than their share, or to take only their share. Strategies available to player 2, the player who waits her turn, are to monitor player 1 or not. Payoffs are calibrated based on a (0,0) benchmark where no stealing and no monitoring take place. If player 1 takes more than his share he gets a benefit B of extra water, and player 2 loses this water, a payoff of -B. Hence, (take your share, do not monitor) can never be an equilibrium (see the arrow pointing downward in Figure 3.6). It costs player 2 an amount (C) to go to the expense of monitoring. So, if player 1 is only taking his share, the outcome to the two players is (0,-C). Thus, (take your share, monitor) can never be an equilibrium (see the arrow pointing across in Figure 3.6).

[Figure 3.6 about here]

This leaves two pure strategy equilibrium possibilities, as well as the possibility of a mixed strategy equilibrium. To spell out these equilibrium possibilities, we must further define the payoff consequences of the situation where player 1 takes more than his share and player 2 monitors. Suppose now that monitoring is imperfect; with probability P, that the player taking more than his share is detected. In this case, player 2 gets all of her water back plus a bonus M for monitoring. Player 1 gets fined P for having taken more than his share. Since monitoring is imperfect; with probability 1-P the player taking more than his share is not detected. The only thing that happens is that player 2 is out the cost of monitoring. According to the expected utility hypothesis"[4] the risk facing each of the players is assessed as follows;

for player 1, $P(-F) + (1-P)(B)$

for player 2, $P(M-C) + (1-P)(-B-C)$

These are the payoffs appearing in Figure 3.6, for the celt corresponding to (take more than share, monitor). The crux of the expected utility hypothesis is that the above payoffs are linear in probability P . -

We now turn to the three possible cases, all of which involve asymmetric equilibria, which can arise in this monitoring game.

Case 1. The pure strategy equilibrium is (take more than share, monitor). This case arises when $P(-F) + (1-P) > 0$, so that the arrow points down in Figure 3.7--case l, and when $-C+PM+(1-P)(-B) > -B$, so the arrow points across.

Case *2.* The pure strategy equilibrium is (take more than share, do not monitor). This case, Figure 3.7-—case 2, arises when $P(-F) + (1-P) > 0$, hence a down arrow, but now $-C +PM+(1-P)(-B) < -B$, reversing the across arrow. Comparing these two cases, one change that could drive a system from case 1 to case 2 would be a big increase in the cost of monitoring C, or a big decrease in the probability of detection P.

Case 3. In this case, Figure 3.7—case 3, $P(-F) + (1-P) < 0$, so the arrow points up, and $-c+PM+(l-P)(-B) < -B$, so the arrow points across. There is no pure strategy equilibrium, as the arrows point to a complete cycle.

However, there is a mixed strategy equilibrium, determined by the conditions that the payoff to monitoring be equal to the payoff from not monitoring for player 2, and the payoff to taking one's share be equal to the payoff for taking more than one's share for player 1. To compute this equilibrium, let t be the probability that player 1 takes more than his share, and let m be the probability that player 2 monitors. The condition that monitoring pays the same as not monitoring is that:

$$(1-t)(-C) + t(-C+PM+(1-P)(-B)) = (1-t)0 + t(-B).$$

The expression on the left represents the expected utility of monitoring; on the right, that of not monitoring. Likewise for player 1, the condition on taking more than one's share is that:

$$0 = m(P(-F)+(1-P)B) + (1-m)B.$$

The expression on the left represents the expected utility of taking one share; on the right, that of taking more than one's share. Denote by (t^*, m^*) the solution to these two equations. Then the mixed strategy equilibrium is given by the probability distribution $(1-t^*,t^*)$ on taking one's share and taking more than one's share respectively for player 1, and the probability distribution $(m^*,1-m^*)$ on monitoring and not monitoring respectively for player 2.

[Figure 3.7 about here]

To summarize the results of the above analysis, we have shown that there is always some tendency to take more water than one's share at equilibrium. This tendency is smaller than one if and only if the detection probability is larger than both the relative benefit of stealing water, $B/(B+F)$, and the cost-benefit ratio, $C/(M+B)$. The parameter regimes for the three different types of equilibria are illustrated by Figure 3.8, which again summarizes our analysis. This figure shows how the equilibrium regimes of a 2-player irrigation game depend on the relation between the relative benefit of stealing water and the cost-benefit ratio.

[Figure 3.8 about here]

In some Instances, the consequences of a change in a variable seem patently clear. Obvious primary effects are often, however, confounded with secondary effects that can easily be overlooked when relying on verbal reasoning. We will investigate several instances where the combination of primary and secondary effects lead to conclusions that are counterintuitive at first sight, but that prove to be quite reasonable after closer inspection. To take a specific example, consider a change in the costs of one player monitoring the actions of another player. Other things being equal, increasing the resources that one farmer must expend to monitor whether another farmer steals water or not, should decrease the rate with which farmers monitor each others' behavior. Decreasing the rate of monitoring, however, leads to an increase in the incentive to steal water. A higher stealing rate, in turn, induces an increase In the rate of monitoring. In this model, the primary and secondary effects offset each other.- We have arrived at the counterintuitive result that a change In the costs of monitoring has no net effect on the equilibrium rate of monitoring.[5]

Even in those cases where the qualitative effects of a change in a variable are unambiguous, more specific information about the strength of this effect is often desirable. Consider a community of irrigators who are faced with the problem of how to reduce stealing. An increase in the detection efficiency of monitoring farmers, a more severe punishment imposed on cheaters, and the employment of an external guard all appear to be appropriate means to reduce the incentive to steal water. Which device, however, is the most effective? This question cannot be addressed without a formal analysis that compares the costs and benefits of accomplishing objectives in a system of complexly interrelated variables.

Conclusions

The particular decision environments we have modeled are topics of considerable relevance for policy analysts in many countries. As we show in later chapters, the levels of appropriation that occur on many CPR-based production systems throughout the world threaten the viability of these systems and the level of agricultural productivity to be derived from these systems. The same is true of the maintenance of such systems. Consequently, the narrow focus of this chapter on simple 2x2 games allows us to address policy questions of importance to the organization of such systems more generally. The same fundamental ideas that apply to 2x2 games apply more generally to mxn games, that is games with m strategies per player and n players. Larger games are of course essential for modelling more complex CPR production systems. We give examples of richer strategy spaces in the next chapter, and of models involving many players in Chapters 9-11, below.

We have given four examples of strategic interactions that naturally occur on CPRs the world over, and shown how game theory can be used to model and analyze such interactions. Our ultimate goal Is to inform policy analysis by employing game theory as a theoretical construct to explain behavior In the action situation. Central to our endeavor is the notion of -strategic equilibrium. It is worthwhile to elaborate further on this crucial notion. Equilibrium is defined by constrained payoff maximization, the constraints including the strategy chosen by the other player. As such, it embodies the basic individual rationality assumptions of neoclassical economics. There are other arguments for strategic equilibrium as well. One argument is based on rational expectations: if every player expects a particular equilibrium to be played, then maximizing behavior will indeed lead to that equilibrium and the expectations are fulfilled. Another argument is metatheoretical. Suppose that a theory of games predicts that equilibria are NOT played. Pick a prediction by this theory and assume every player is playing according to this theory. Then, at least one of the players is not maximizing his payoff. Such a player has an incentive to disobey the theory. This makes the theory self-defeating.

Game theory as currently practiced is predicated on the notion of strategic equilibrium. Since this is a theory of play by rational beings, one should not be overly surprised when one encounters data from human play which is not entirely consistent with it. Although the ability of game theory to explain the data we present is remarkably good, it is far from perfect. There are several reasons for the imperfect fit. First, the players may not completely understand the game. It may be that only through repeated play over time can they come to learn and understand the rules of the game and learn how best to play the game. Second, even if the players completely understand the game, their motivation may be limited to some extent by factors outside game theory, such as rounding off of payoffs, limited computational abilities, or cognitive processing of the task which suppresses some of its strategic content. All of these possibilities fall under the rubric of bounded rationality, an important topic to which we devote our final chapter. Third, the notion of utility used in game theory may not be entirely appropriate. If there is latent altruism present among the players, then individualistic utility misspecifies the true payoffs. In such cases, notions of fairness may intrude and decisively alter the character of play. Despite the empirical importance of such deviations from equilibrium play, equilibrium itself still represents the best way of first organizing the data, even if further analysis of deviations from equilibrium proves necessary.

Figure 3.1. The 2X2 Game

		PLAYER 2	
		STRATEGY 1	STRATEGY 2
PLAYER 1	STRATEGY 1	a a	b c
	STRATEGY 2	c b	d d

Figure 3.2. The Prisoner's Dilemma Game a>d, d>b, c>a

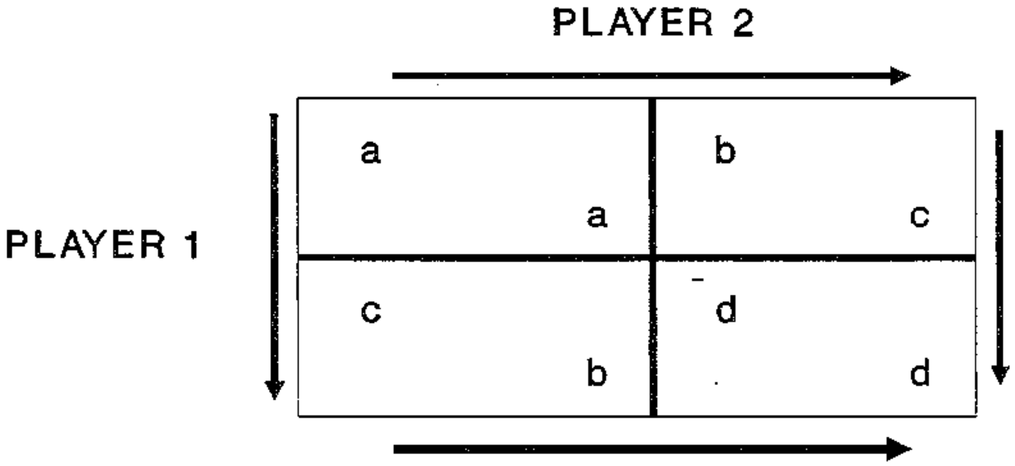
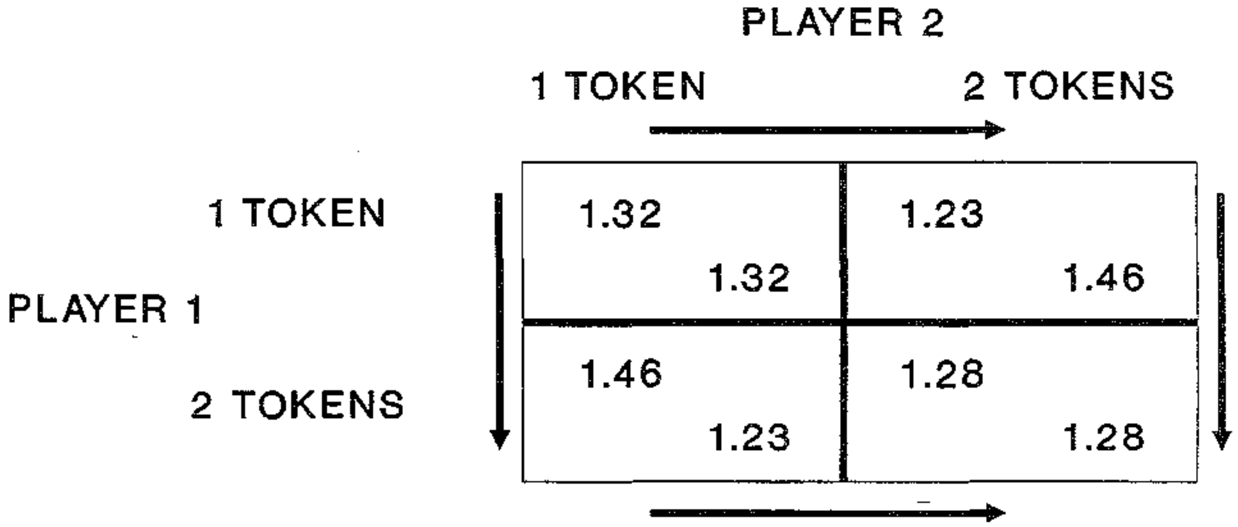


Figure 3.3. Suboptimal Allocation



		PLAYER 2	
		1 TOKEN	2 TOKENS
PLAYER 1	1 TOKEN	1.32 1.32	1.23 1.46
	2 TOKENS	1.46 1.23	1.28 1.28

		PLAYER 2	
		1 TOKEN	2 TOKENS
PLAYER 1	1 TOKEN	t+(1/2)[2-a*4] t+(1/2)[2-a*4]	t+(1/3)[3-a*9] (2/3)[3-a*9]
	2 TOKENS	(2/3)[3-a*9] t+(1/3)[3-a*9]	(1/2)[4-a*16] (1/2)[4-a*16]

Figure 3.4. The Assignment Game

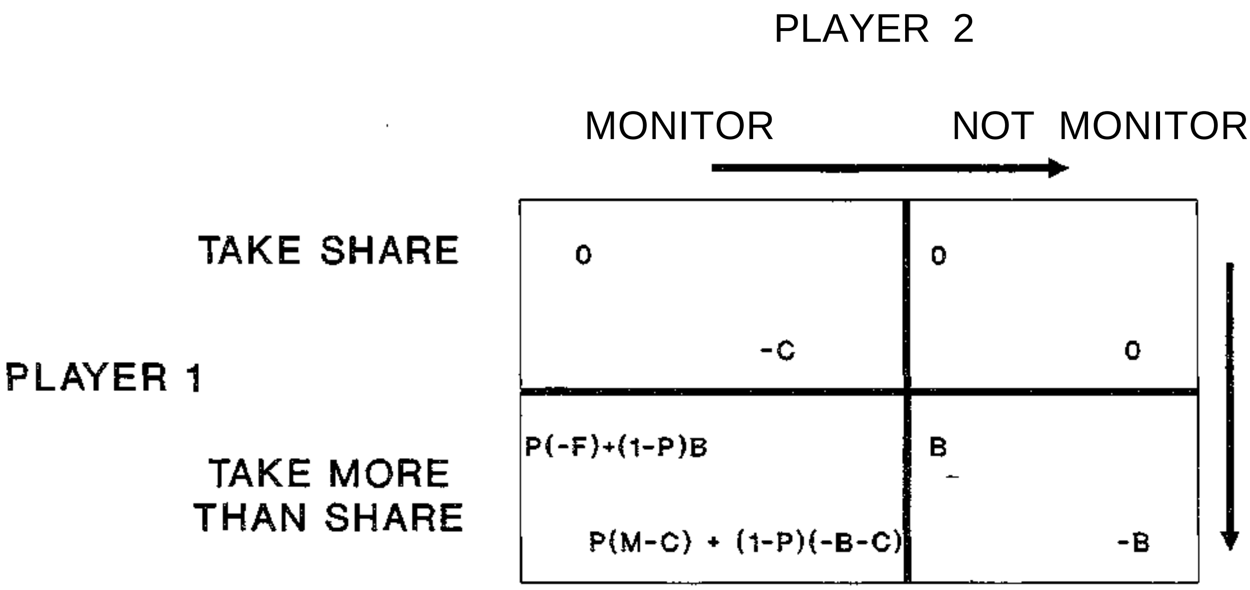
		Player 2	
		FISH SPOT 1	FISH SPOT 2
Player 1	FISH SPOT 1	V1/2 V1/2	V1 V2
	FISH SPOT 2	V2 V1	V2/2 V2/2

Figure 3.5. The Provision Game

		PLAYER 2	
		CONTRIBUTE	NOT CONTRIBUTE
PLAYER 1	CONTRIBUTE	1.5 1.5	.75 1.75
	NOT CONTRIBUTE	1.75 .75	1 1

		PLAYER 2	
		CONTRIBUTE	NOT CONTRIBUTE
PLAYER 1	CONTRIBUTE	1.5 1.5	1 0
	NOT CONTRIBUTE	0 1	1 1

Figure 3.6. A Monitoring Game



		PLAYER 2	
		MONITOR	NOT MONITOR
PLAYER 1	TAKE SHARE	0 $-C$	0 0
	TAKE MORE THAN SHARE	$P(-F)+(1-P)B$ $P(M-C) + (1-P)(-B-C)$	B $-B$

Figure 3.7. The Monitoring Game: 3 Cases

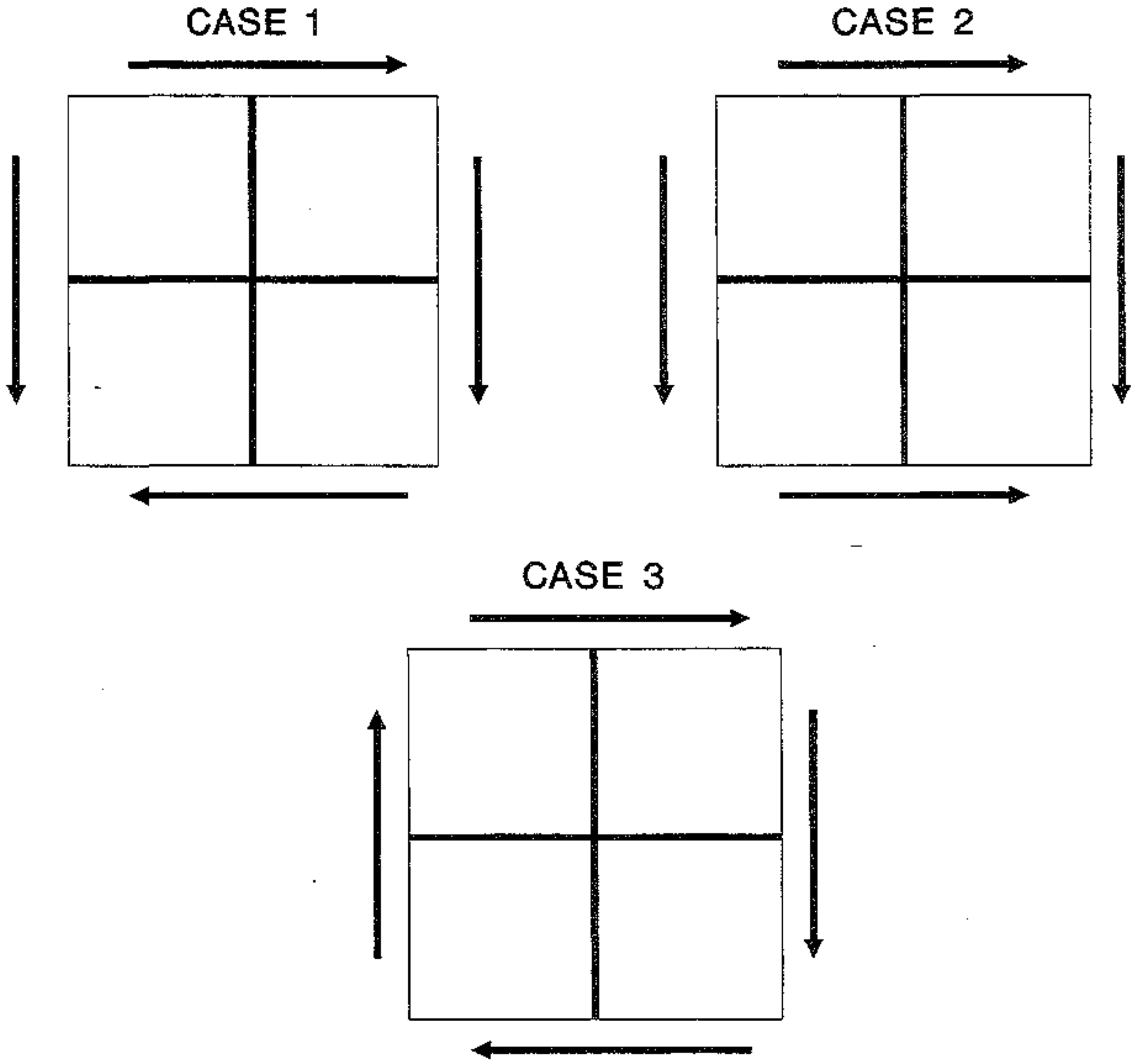
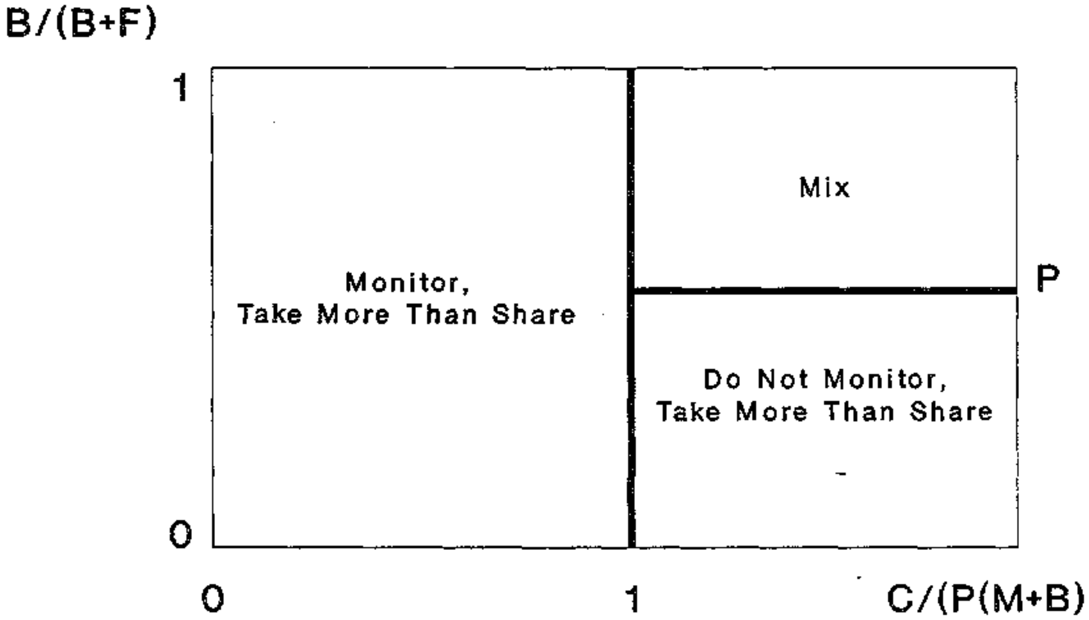


Figure 3.8. Regime Diagram fo the Monitoring Game



Notes to Chapter 3

1. A Pareto inferior outcome is one where it is possible to make every player better off by some alternative choice of strategies.

2. Harsanyi and Selten (1988) have created a general theory for selecting among multiple equilibria in games. Their axioms lay great stress on symmetries, where available, and on attitudes towards risk. Although their theory is controversial, it is the first one available for dealing with the thorny problem of multiple equilibria in a consistent fashion.

3. This section is based on Wessing and E. Ostrom (1991). Further, explanation and extensions can be found there.

4. As a tool for modelling, we will adopt the expected utility hypothesis throughout the book. Despite its empirical problems, it is still the simplest hypothesis to handle the various complications that arise when dealing with situations involving risk.

5. The existence of offsetting primary and secondary effects in many types of social situations where rational "opponents" interact with one another is the major subject of Tsebelis (1989, 1990, 1991). See Weissing and E. Ostrom (1991) for a clarification for Tsebelis's argument.

CHAPTER4.DRF
October 16, 1991

Chapter 4

Rules and Games

In this chapter we investigate further the formal connection between rules and games discussed in Chapters 2 and 3. The connection between rules and games among the founders of game theory was clear. The rules of a game were equated with the game structure itself. In the words of von Neumann and Morgenstern {1964, 49); "The game is simply the totality of the rules which describe it." Using the language of institutional analysis, one could reinterpret this assertion as denying the analytical separation of the action situation, on the one hand, and states of the world, rules, and community, on the other hand. If rules were to be equated with the game itself, *no* further investigation would seem necessary.

Two things are worth pointing out. First, games are nowadays described by mathematical objects-—set functions, matrices, trees, and the like—while rules require a somewhat different description. Statements that currently belong to the game-theoretic category of "the rules of a game" include both physical and deontological statements.

Second, physical regularities and deontic regularities are subject to different forms of change. Human Intervention cannot change fundamental physical regularities, such as the laws of physics and biology. People can use knowledge about fundamental physical and biological regularities, however, to develop new technologies that reduce the cost of many actions. While water will not "flow" upstream in a natural watercourse, water can be lifted over physical barriers at costs that technological improvements may reduce. Change is wrought by using the knowledge of physical laws to find mere efficient uses of energy or new combinations of raw materials rather than by changing physical laws themselves.

Deontic regularities, by contrast, exist primarily within a human domain. These regularities involve what people perceive to be the right or wrong actions to take or states of the world to affect In particular kinds of situations. As such, deontic regularities are context-specific constraints that human beings create and change by self-conscious choice or by evolutionary processes not involving self-conscious choice. Many efforts to improve human welfare include changing deontic regularities.

Physical statements tell what players are expected to find physically necessary, possible, or impossible to do. *Deontological statements* tell what players are expected to find obligatory, permitted, or forbidden to do. We can describe physical statements by nomological techniques and deontological statements by deontic techniques.

Game theory ordinarily takes a particular game as given and proceeds to predict outcomes. We posit a set of physical and deontic statements and examine how these affect game structure.[2] Then we embed the solution of a game (the predicted outcomes) within these physical and deontic constraints. We portray this schema in the following manners

Physical statements ↘
Deontic statements ↗ ----------------------> **Games** ------------> **Outcomes**

When rules or deontic statements are changed, the resulting games may produce incentives leading to the same, improved, or worse outcomes for the participants.[3] Of special interest to policy analysts are rule changes that lead to improved outcomes, or in a word, reforms. It seems hardly a coincidence that Bentham coined words such as "deontological" and "maximization." Bentham was first and foremost a reformer. He created an entire vocabulary of social reform that we still use today.

If we want to make only single comparisons and not set comparisons (as we shall in this chapter), then we use *equilibrium point selection theory* to select a unique equilibrium point In each game or subgame we encounter (Harsanyi and Selten 1988). The game-outcome function then induces a particular ordering among (deontic) rule configurations. In particular, a game is reformed when the rules are changed in such a way as to increase the net total yield to the players. In this chapter we examine the relationship between rules and games without attempting to model the processes of rule selection. We focus on a series of fishing assignment games and some of the sets of rules that affect their structure. Much of the world's fishing occurs in contested waters. Conflicts arise between nations when international conventions such as the 200 mile limit collide (Canada vs. France, U.K. vs. Iceland, U.K. vs. Belgium). Even more frequently, conflicts arise in those coastal or inland waters where neither property rights nor user rights are clearly defined (see Clugston **1984;** Pollack 1983).

How Rules Affect the Structure of a Game

Equating the structure of a game with the rules of a game has served game theorists well in the development and application of rigorous methods for discovering equilibria in given situations. Everything that affects the structure of the game has been grouped together under the term "the rules of the game." As Shubik (1982, 8) expressed this concept, "the rules of the game include not only the move and information structure and the physical consequences of all decisions, but also the preference systems of all the players." Further, the rules have been viewed as "absolute commands" that are never infringed (von Neumann and Morgenstern 1964, 49). As long as the focus of game theory was on the analyses of equilibria within given games, equating the game with the rules of the game was a useful simplification.

Recently, however, game theory also has become a theoretical tool of analysis for exploring the effect of different property rights systems (rules defining who has rights and duties and what these are) in conjunction with particular physical domains such as various kinds of resource systems (Kaitala 1986; Clark 1980; Plott and Meyer 1975). In this kind of analysis, the structure of a game and its equilibria are implicitly viewed depending on: (1) a set of institutional rules interpreted as different and apart from the game itself and (2) the kind of physical domain under study. In such analyses the structure of the physical domain is often well specified. Clark (1980), for example, presents a basic model of a commercial fishery composed of six equations containing eleven variables. Having laid out the structure of the physical domain, Clark proceeds to analyze the equilibria yielded under several property rights regimes including limited-access, open-access, quantity controls, and various forms of licenses and taxes. While the effects of the rules on the game are well specified, the rules themselves, if not implicitly assumed, are only broadly alluded to by analysts.

As the work of game theorists has evolved, they have distinguished implicitly between the rules of the game and the game itself. In addition, within the concept of the rules of the game, further distinctions separately identify institutional rules and the regularities present in physical and biological domains. The structure of a game and its equilibria can be analyzed as resulting from the operation of a set of rules in combination with the characteristics of a particular physical and biological domain. These distinctions lead to eight cases (see Table 4.1). The first case where the physical and biological domains as well as the rules remain the same (s) is tautological. The second case is impossible. The third case, where institutional rules are different (d) while the physical and biological domain remain the same and no change in outcome occurs, is a rarely contemplated, but an important case. A change of rules that does not change outcomes is a futile change. The fourth case appears frequently in the game-theoretic literature applied to resource problems (Kaitala 1986; Clark 1980f Plott and Meyer 1975). In this instance, a change in the rules does yield a change in outcomes.

[Table 4.1 about here]

The fifth case helps to identify the robustness of a set of rules. If the physical domain changes while rules and outcomes remain the same, a particular set of rules can apply to a broader set of physical conditions. In a similar vein, the sixth case helps to identify the limitations of a set of rules. The seventh and eighth cases allow simultaneous difference in both the physical domain and the rules-in-use. While often encountered in analysis of natural settings, these cases are analytically less attractive to examine than cases (3) through (6). Once we decouple rules and games, however, six nontautological possibilities can logically happen and require examination.

Because past emphasis in game theory has been on the structure of a game, no systematic effort has been devoted to developing a common, theoretical language to describe rules and to aid in the analysis of the effects of rules on game structure and patterns of outcomes. To undertake institutional analysis using a game-theoretic approach, one needs a system for analyzing rules and a criterion for evaluating when a rule change makes a difference. As we discussed in Chapter 2, rules are prescriptions that participants commonly know and use to order repetitive, interdependent actions situations that can be modeled as formal games. Prescriptions refer to which actions (or states of the world) are permitted,, obligatory, or forbidden. Rules may result from self-conscious choice or may evolve over time as people develop shared understandings of what actions or outcomes may, must, or must not be done in particular situations (Commons 1957; Hayek **1973;** V. Ostrom 1980).

The basic elements of a game, as described in Chapter 3 are: (1) a set of players, (2) a set of positions, (3) sets of actions assigned to positions at choice nodes including chance moves, (4) a decision function- that maps choices into intermediate or final outcomes, (5) a set of outcomes, (6) the kind of information available at a node, and (7) payoffs based on benefits and costs of actions and outcomes. Rules directly and indirectly affect the structure of a game by changing these key elements. A rule that forbids players to produce a particular outcome, for example, indirectly will affect the set of actions available to the player. Alternatively, rules that create or destroy strategies have a secondary impact on the entire shape of the tree and potentially on outcomes. As discussed in Chapter *1,* we classify rules into seven broad varieties depending upon which element of a game the rule directly, rather than indirectly, affects. We cluster together rules that directly affect the set of actions available to a player at a choice node, for example, in what we call "authority rules." We call rules that directly affect the benefits and costs assigned to actions and outcomes "payoff rules" (see Chapter 2 for further examples).

From an examination of the game tree and payoff parameters, one cannot know what configuration of rules shaped the tree and determined the parameters. An outcome may be present or missing or positively or negatively valued as a result of the operation of several rules together rather than of any single rule. Rules frequently operate configurally; that is, a change in one rule affects how other rules are expressed in the structure of the game. Thus, inferring rules from the structure of a game tree is a theoretically treacherous endeavor. Developing a technical language about rules and their relationship to game structure and outcomes is an important step in the development of more rigorous theories about the effects of institutions.

In analyzing the institutional rules of a game, one should expect to find at least one rule, and commonly more, from each of the seven kinds of rules. Because sets of rules often operate in a configural or interactive manner, one needs to examine the effects of a full rule configuration rather than the operation of a single rule. To do this, it is necessary to specify a default rule that is considered present if no other rules has taken is place.[4] The seven default rules ares

Default Position Rules There exists one position.

Default Boundary Rules Any player is permitted to enter or leave any position in the game.

Default Authority Rules Any player is permitted to take any physically possible action at any node of the tree.

Default Aggregation Rules Players are permitted to act independently. Physical relationships present in a domain entirely determine the aggregation of individual moves into outcomes. (Note: If a rule configuration contains only a default authority rule, the default aggregation rule MUST be present.)

Default Scope Rules Any player is permitted to affect any state of affairs that may be physically affected.

Default Information Rules Any player is permitted to communicate any information _via_ any channel and language available to the player.

Default Payoff Rules: Any player is permitted to retain any outcome that the player physically can obtain and defend.

If all of the rules are set at their default position, the resulting rule configuration operationalizes Hobbes's concept of the "state of nature." The only factors affecting the structure of a game in a "state of nature" are those related to the physical domain in which the game is played. As more and more rules are changed from a default condition, the options available to players are less and less controlled by the physical domain and more and more controlled by human prescriptive intervention. Clearly, not all rule changes imply an improvement.

Some Empirical Examples

These concepts are relatively abstract. Before we develop our formal argument further, we present some empirical examples of assignment problems related to fisheries where different rules are in use.

An *Assignment Problem without Effective Rules*

On December 23, 1970, fifty trawlers were fishing inshore off the northwest coast of West Malaysia and were challenged by ten inshore boats from neighboring villages. The trawlers caught one of the boats and burned it. They "slashed two captured crewmen with knives, and left them to sink or swim (they survived)" (Anderson and Anderson 1977, 272). Three nights later, a larger group of inshore boats chased the trawlers and caught one of them.

> The crew of five promptly got off into the water. Two could not swim. One was caught and slashed deeply on the arms with a large cleaver, but managed to escape and cling to a net-float. One was forced into the water and never seen again. The trawler was burned; the hulk, burned to the waterline, was towed to Kampong Mee, where the injured fisherman told his story while waiting for the ambulance (Anderson and Anderson 1977, 272).

Both the trawlers and the inshore fishermen preferred to fish in the rich waters within three miles of the shore. While national legislation was on the books to exclude trawlers from this zone, trawlers totally ignored this legislation. No *effective* rules limited the actions of either the trawlers or the inshore boats. In other words, most of the rules were effectively at a default level. Between October 1970 and October 1971, over forty boats were sunk and at least nine fishers were killed. To quell this fishing war, the Malaysian government finally sent in over l,000 soldiers and jailed more than twenty men without trial. A "peace commission," formed by the national government, brought about a truce of sorts (Anderson and Anderson 1977, 274. The conflict continued to simmer, however, for at least five additional years.

Examples of violence erupting over contested fishing waters is not limited to remote locations in West Malaysia. Fights among fishers have erupted on the Great Lakes, in the English Channel and North Sea, and elsewhere. External authorities may try to impose order or pass legislation that allocates such contested waters. Unless the fishers themselves accept legislation as effective rules, however, they continue to play the fishing game as if the legislation did not exist. The probability of violence is ever present.

In addition to the many locations where no effective rules limit who can fish in which locations, fishers living in some regions have devised relatively stable rule systems that have reduced the level of violence substantially and have produced various kinds of equilibria. A classic rule of allocation used throughout the ages to settle disputes over who can use particular locations for particular purposes is "first in time, first in right."[6] While this rule is not used extensively among inshore fishers, it is used along the shores of such diverse countries as India and Brazil (Raychaudhuri 1980; Forman 1970).

The Use of "First in Time, First in Right" Rules

Along the West Bengali coast, fishers use a series of flat, swampy islands for four to five months each year during the season when large shoals of fish can be expected to appear. Fishers who settle temporarily on the Island of Jambudwip set large nets on wooden posts in semi-permanent locations for the duration of the fishing season. The value of the catch depends on the skill of the fishing team in finding a good location and in setting the net properly. Further, the direction of the shoals of fish can change, necessitating a change in the location of the nets if a fishing team is to make a good harvest. The basic rule used on this island is that the first team to set a net in a particular fishing spot has a right to continue to use that location throughout the season.

> If a fishing unit changes its phar (wooden posts, etc. with which the nets are set) and sets up a new one in another place, no other fishing unit has the right to set its net in that deserted phar . . . throughout the season without prior permission. The owner may, however, set his net again in that deserted phar if the shoal of fish takes that direction. . . . Thus, the fisherfolk have developed a conventional moral code of non-encroachment among themselves for their livelihood. This may be termed as their tenure system valid for one fishing season only (Raychaudhuri 1980, 168).

Among the raft fishermen who ply some of the coastal regions of Brazil, the first raft to settle in a particular location for a day has the right to continue to use the location undisturbed by other rafts. These "temporary usufructory property rights" allow fishers to change locations from day to day without conflict (Forman 1970, 74; Kottak 1966, 224).[7]

The Use of Prior Announcement Rules

The impoverished fisherfolk who live along the shores of Bahia in the northeastern part of Brazil have devised a more extended set of rules that effectively assign "sea tenure" rights to the captains of canoes working in the mangrove swamps along the shore. The forms of sea tenure used in Bahia have evolved from the practices of the fisherfolk themselves, are unacknowledged by governmental authorities, and are contrary to national legislation stipulating that territorial waters are public property. Around the port of Valena, the local fishers have identified, mapped, and named 258 fishing spots, so that fishing in one spot does not interfere with fishing in the other spots. Some spots are owned permanently by the captain of a boat. The fishers have agreed that the captains from a particular village can use other spots sequentially over time. When a captain wishes to fish in a spot, he records his plans in a public forum—-the local bar—and marks the location where he intends to fish.[8]

> All that is required is for another fisherman to be present as a witness. To ensure the claim, the captain must follow his proclamation by going to the chosen spot the day before fishing to leave a canoe anchored with paddles sticking up in the air. This forewarns competitors that the casting space has been taken. Fishing captains go to considerable lengths to support each other in this routine, which is part of the sea tenure politics that shore up the entire fishing system (Cordell and McKean 1986, 96).

The Use of Prearranged Rotation Rules

In some regions of the world, overt rotation systems have been developed to assign fishing spots on an equitable basis to all eligible fishers. A lottery-rotation system, developed by the inshore fishers living in Alanya, Turkey, is among the most intriguing. Prior to their invention of this set of rules, they had suffered considerable conflict over access to the better fishing spots in the local fishery (Berkes 1986, 73). The fishers of Alanya mapped and named all the spots where setting a net in one spot did not block the flow of fish to an adjacent spot. In September of each year, the licensed fishermen in the village draw lots to gain assignment to a specific fishing location for the first day of the season. "Prom September to January, each fisherman moves each day to the next location to the east. After January the fishermen move west. This gives each fisherman an equal opportunity at the stocks that migrate east to west between September and January, and reverse their migration from January to May through the area" (Berkes 1986, 74). This system is relatively easy to monitor and enforce, and it has been maintained for over 15 years, primarily through the verbal and physical actions of the fishers themselves. "Violations of the rule of assigned locations are dealt with by the fishing community at large, in the coffee house" (Berkes 1986, 74). Other lottery systems, such as the one that cod fishers in Fermeuse, Newfoundland, use, assign a location to a fisher for an entire season. In Fermeuse an elected committee of local fishers runs an annual lottery to assign trap locations, or "berths," to fishers from the local village for use during the summer season (Martin 1979, 282). During the rest of the year, traps are not an effective technique for capturing cod, and Fermeuse fishers have divided their local fishery into distinct zones assigned to boats using a particular technology.

Fishing Rules and Fishing Games

An Overview

The preceding descriptions provide a brief overview of some of the wide diversity of rules used in practice to assign locations of diverse value to fishers.[9] The lack of an accepted rule that makes a clear assignment of authority regarding who can use a particular location under what circumstances —as in the first example from West Malaysia—is likely to lead to conflict and violence. Many specific kinds of authority rules that make clear assignments are possible. Each kind of rule combined with the physical and biological domains in which people use them may (or may not) change the structure of a game sufficiently to produce different equilibria and potentially different welfare distributions.

To illustrate how rules combined with physical domains affect the structure of games and resulting equilibria, we analyze four stylized rule configurations, which we purposely keep as simple as possible. We assume that all rules, except the authority rule and position rules, are set at the default condition. This means that the rules allow fishers to act independently, to affect any outcome that they can physically affect, to communicate or not with one another without restrictions or enhancements, and to retain the fish that they capture without external rewards or costs being imposed on them. By setting the remaining rules at a default level, one can focus exclusively on the effect of changes in the authority of fishers to use a fishing location in which to fish without considering how various boundary or payoff rules would interact with a specific authority rule.

The problem we focus on in this chapter is an assignment problem that occurs when there is competition among users of a common-pool resource for limited use of diverse space or periods of time (see discussion of assignment problems in Chapter 1). The problem to be examined is not that the resource is being harvested at a non-optimal rate or that it is about to be destroyed. The problem is simply that some fishing spots are better than others, leading to conflict over who may fish where. Assignment problems are involved in many situations involving major inter- and intra-national conflict and warfare.

The Formal Game

This section studies the impact of various rule configurations on a simple model of a fishing location, non-cooperative, assignment game (Gale and Shapley 1962).

We will construct a simple model of a fishing game that is the result of both particular combinations of physical and biological variables and rule configurations. Our physical and biological world for two fishers is composed of the relative value of fishing spots, the relative amount of damage that one fisher can inflict on another, the cost of traveling to a fishing spot, and the relative strength of fishers. We first examine a near Hobbesian rule configuration where all rules, except the position rule, permit any physically possible state of affairs to happen. In those physical domains in which the amount of damage that one fisher could inflict on the other is relatively mild, we could expect fishers who both arrive at the better fishing spot to fight for it unless they are pitted against a very much stronger player. We also expect stronger fishers to fight for the less valuable spot if need be. When we combine the same Hobbesian rules with an environment in which potential damage is severe, the likelihood of fighting changes substantially. So long as both fishers retain a rational approach to the analysis of their relative advantage, a large zone of outcomes exists in which no fighting will occur, and when it does, fighting over the less valuable spot is even less likely to occur.

Changing the authority rule to a "first in time, first in right" rule dramatically affects the structure of the game. All moves after the first two are truncated. The change in rules eliminates fights and thus damage from fights. The change in rules also produces an equilibrium for all potential physical domains that is equivalent to the equilibrium produced in only a subset of the physical domains combined with Rule Configuration Cl. Thus, for some physical domains, moving from Cl to C2 represents a welfare improvement and a reform. Further, even in those physical domains where rational fishers will not fight, adopting the rules of C2 prevents the kind of fights that might occur when fishers deviate from equilibrium play.

Expanding the authority rule contained in C2 to allow a prior announcement to give a fisher the right to fish in a spot for a day produces a game in which neither player has to pay the cost of traveling to two spots during one day. So long as the assignment of a fisher to the position of player 1 is random, C3 produces a game with a symmetrical payoff and reduced costs. The last rule configuration we analyze contains an overt rotation rule that removes all strategic calculations from the model, and the "game is gone.™ There are two fishers, denoted 1 and 2, and two fishing spots. Each fishing spot i has a value in terms of fish caught of vi, with spot I being better than spot II,

$v_I > v_{II}$ (1)

(1) Travel to a fishing spot or from one fishing spot to another costs a fisher c fish, with c smaller than the value of the poorer spot,

$v_{II} > c$ (2)

Given that the value of one fishing spot exceeds that of the other, and, that the default authority rule does not restrict the actions that can be taken, fights can occur. Each fisher can inflict damage in the amount d on the other. Damage can vary from mild to serious, depending on the size of d. Damage may vary from the cutting off of a fishing trap, the destruction of nets and fishing gear, all the way to serious harm inflicted on persons and

boats. We classify the damage as serious if damage outweighs the value of fishing on the second best spot:

$$d > v_{II} \qquad (3)$$

Damage is mild if:

$$d < 2c - v_{II} \qquad (4)$$

Values of damage between v_{II} and $2c - v_{II}$ are called intermediate. The reason for this distinction becomes clear when we analyze the rational choices of fishers playing this game. As we shall see, the fighting environment has a substantial impact on the way rational fishers interact with each other.

These physical characteristics apply across all rule configurations. Thus, the physical statements that one can make about this game relate to; (1) the value of the fishing spots, (2) the amount of damage that one fisher can inflict on another, (3) the cost of traveling to a fishing spot, and (4) the relative strength of fishers. Combinations of these physical variables constitute various physical domains.

In Table 4-2, we array four extremely simple rule configurations. The entry of a "one" in a column depicts that the rule is present while a "zero" depicts its absence. The first rule configuration, Cl, is primarily composed of the default rules as previously enumerated, with the exception of the position rule, which creates two preassigned positions—Player 1 and Player 2 —and which allows the physically stronger player to play in Position 1. Many factors may make one fisher physically stronger than another. The boat that one fisher uses may be larger and able to inflict more damage if it runs over the nets of the other fisher. Or, one fisher may simply be a larger person and more likely to inflict physical damage on the other if they were to get into a fight. Other than this position rule, Cl places no limits on the actions a player can take, on the outcomes that can be reached, on the information that can be exchanged, or on the payoffs assigned to actions or outcomes. In a word, Cl describes a Hobbesian fishing world.

[Table 4.2 about here]

Figure 4.1 portrays the extensive-form game to which rule configuration C1 leads. Player 1, moving first, travels to either fishing spot. Player 2, moving second, and not observing player 1's movement, travels to either spot. If both spots are taken, the game ends. Otherwise, both fishers are on the same spot and a fishing fight is possible. Suppose that both fishers are on spot I. If each decides to stay on the spot, they fight for possession. With probability p, fisher 1 takes the spot and fisher 2 suffers damage, whereas the opposite occurs with probability (1-p). Writing W_{I1} for $pv_I - (1-p)d$ and W_{I2} for $(1-p)v_I-pd$, one has the payoffs

$$W_{I1} - c \qquad (5)$$

and

$$W_{I2} - c \qquad (6)$$

for fishers 1 and 2, respectively. The probability p allows for differences in fighting ability between the fishers. Since d is positive, $W_{I1} \leq v_I$, $W_{I2} \leq V_{II}$, fighting impairs costs on both parties. If precisely one fisher leaves the spot, the game ends with the payoffs

$$(v_I - c, v_{II} - 2c),$$

depending on which fisher leaves. Finally, if both leave the spot, they find themselves on the other spot. In this event, the game ends with a fight on spot II, in which event player 1 gets

$$W_{II1} - 2c \qquad (5)'$$

and player 2 gets

$$W_{II2} - 2c. \qquad (6)'$$

Here $W_{II1} = pv_{II} - (1-p)d$, and $W_{II2} = (1-p)v_{II} - pd$.
The strategic continuation if both fishers begin on spot II is analogous.
[Figure 4.1 about here]

To analyze the play of the game governed by rule configuration C1, we assume that the players play a subgame perfect equilibrium (Selten 1973). One can identify such an equilibrium by backward induction: make your best move at the end of a game, then make your best move at the next-to-last move of the game, based on your best move at the end of the game, and so on. To analyze the fishing game in this way, we begin by considering the final subgames when both fishers have arrived on spot I.

They face the matrix subgame as shown in Game 1.

Game I

1 \ 2	stay	leave
stay	$W_{I1}-c$ $W_{I2}-c$	v_i-c $v_{II}-2c$
leave	$v_{II}-2c$ v_I-c	$W_{II1}-2c$ $W_{II2}-2c$

Since $v_I - c > W_{IIi} - 2c$ for either i, (leave, leave) is not an equilibrium. These equilibria are possible: (fight, fight), (leave, fight), (fight, leave), or completely mixed. Figure 4.2 depicts these possibilities. Equilibria are unique except when v_{II} and v_I nearly equal in fishing value and the fishers are nearly equal in fighting ability. In this case we use Harsanyi-Selten selection theory to identify one of these equilibria for rational play. For $p > 1/2$, the players choose tie equilibrium (fight, leave); for $p < 1/2$, (leave, fight); for $p = 1/2$, the completely mixed equilibrium. Rational play supports the maxim "might makes right"--the mightier fisher gets the better spot (see also Umbeck 1981).

[Figure 4.2 about here]

We now consider the situation that faces the fishers if each has traveled to spot II initially. The matrix subgame facing them is the one shown in Game 2.

Game 2

1 \ 2	stay	leave
stay	$W_{II1}-c$ $W_{II1}-c$	$v_{II}-c$ v_I-2c
leave	v_I-2c $v_{II}-c$	$W_{I1}-2c$ $W_{I2}-2c$

The equilibrium point possibilities, depicted in Figure 4.3, here are somewhat richer than on spot I. If spot I is valuable enough, then both fishers will leave for it and fight it out: (leave, leave) is the equilibrium. But, if both spots are nearly equal in value and p is nearly one-half, then they stay on spot II and fight it out: (stay, stay) is the equilibrium. Between these two zones is a zone of multiple equilibria: (leave, stay), (stay, leave), and completely mixed. Again using selection theory, when $p > 1/2$, (leave, stay) is played; when $p < 1/2$, (stay, leave); when $p = 1/2$, completely mixed.

[Figure 4.3 about here]

It is worth pointing out two implications of the level of damage for willingness to fight. First, if damage is serious, then equilibria of the form (stay, stay) on spot II disappear. Suppose not. Then it follows from adding

$$W_{II1} - c > v_I - 2c$$

and

$$W_{II2} - c > v_I - 2c$$

that

$$v_{II} - d > 2(v_I - c). \qquad (7)$$

Inequality (7) is contradicted when damage is serious. Second, if damage is mild, then someone is always willing to fight for something. Suppose not. Then no one would find spot I worth fighting for, even if he or she were already there. It then follows from

$$W_{I1} - c < v_{II} - 2c$$

and

$$W_{I2} - c < v_I - 2c$$

that

$$v_I - d < 2(v_{II} - c). \qquad (8)$$

Inequality (8) must hold even in the limit as $v_I - v_{II}$. For v_I close enough to v_{II}, however, (8) implies that $2c - v_{II} < d$, contradicting the hypothesis that damage is mild.

Willingness to fight determines equilibrium play on a fishing spot when both fishers have arrived there. This determination further allows us to complete the backward induction to the initial moves, leaving a 2 x 2 matrix game to consider. To complete the backward induction, we must solve the first stage game in which the players simultaneously choose a spot to which to travel. Which spot that will be depends on what one can rationally expect to obtain in the second stage. It turns out that there are five major physical domains leading to five different first stage matrix games. We now proceed to enumerate these five physical domains.

<u>Domain C1-1</u>. This domain is described by the inequalities

$$W_{I2} > v_{II} + c,$$

$$W_{I1} > v_{II} + c.$$

If both fishers are on spot I, they fight; if both are on spot II, they leave for spot I and fight. This leads to the first move matrix game:

1 \ 2	travel to spot I	travel to spot II
travel to spot I	$W_{I1}-c$ $W_{I2}-c$	v_I-c $v_{II}-c$
travel to spot II	$v_{II}-c$ v_I-c	$W_{I1}-2c$ $W_{I2}-2c$

This game has a unique equilibrium point: (travel to spot I, travel to spot I). The perfect equilibrium on this domain is "go to the better spot and fight."

Domain C1-2. This domain is described by the inequalities:

$v_{II} - c < W_{I2} < v_{II} + c,$

$W_{II1} < v_{II} + c < W_{I1},$

$p > 1/2.$

If both fishers are on spot I, they stay and fight; if both are on spot II, fisher 1 leaves and fisher 2 stays. The matrix game is shown in Game 3.

Game 3

1 \ 2	travel to spot I	travel to spot II
travel to spot I	$W_{I1}-c$ $W_{I2}-c$	v_I-c $v_{II}-c$
travel to spot II	$v_{II}-c$ v_I-c	v_I-2c $v_{II}-c$

This game has a unique equilibrium point (travel to spot I, travel to spot II). The better fighter gets the better spot.

There is a mirror image to this domain, in which fisher 2 is the better fighter. In this domain, when both fishers are on spot II, fisher 2 stays and fisher 1 leaves.

Domain C1-3. This domain is given by the inequalities

$W_{I1} > v_{II} + c,$

$W_{I2} < v_{II} - c,$

$p > 1/2.$

If both fishers are on spot I, fisher 1 stays and fisher 2 leaves. If both fishers are on spot II, fisher 1 leaves and fisher 2 stays. This leads to Game 4:

Game 4

1 \ 2	travel to spot I	travel to spot II
travel to spot I	v_I-c $v_{II}-2c$	v_I-c $v_{II}-c$
travel to spot II	$v_{II}-c$ v_I-c	v_I-2c $v_{II}-c$

This game has a unique equilibrium point (travel to spot I, travel to spot II). Again, the stronger fighter gets the better spot.

There is a mirror image to this domain, in which fisher 2 stays on spot I and leaves spot II.

<u>Domain C1-4</u>. This domain is given by the inequalities

$W_{I2} < v_{II} + c,$

$W_{I1} < v_{II} + c,$

$W_{II1} > v_I - c,$

$W_{II2} < v_I - c,$

$p > 1/2.$

If both fishers are on spot I, fisher 1 stays and fisher 2 leaves; if on spot II, fisher 1 again stays and fisher 2 leaves. The matrix game is shown in Game 5.

Game 5

I \ 2	travel to spot I	travel to spot II
travel to spot I	v_I-c $v_{II}-2c$	v_I-c $v_{II}-c$
travel to spot II	$v_{II}-c$ v_I-c	$v_{II}-c$ v_I-2c

There is a unique equilibrium (travel to spot I, travel to spot II). In the mirror image domain, fisher 2 stays on the spot and fisher 1 leaves.

Domain C1-5. This domain is given by the inequalities:

$W_{II1} > v_I - c,$

$W_{II2} > v_{II} - c.$

If both fishers are on spot I, they stay and fight; if both are on spot II, they again stay and fight (see Game 6).

Game 6

I \ 2	travel to spot I	travel to spot II
travel to spot I	$W_{I1}-c$ $W_{I2}-c$	v_I-c $v_{II}-c$
travel to spot II	$v_{II}-c$ v_I-c	$W_{II1}-c$ $W_{II2}-c$

The unique equilibrium point is (travel to spot I, travel to spot I). Both fishers go to the better spot and fight.

We summarize the perfect equilibrium play according to rule configuration Cl in Table 4.3 for each of the physical domains. On domains Cl-2 to Cl-4 the perfect equilibrium outcome is Pareto-optimal and so cannot be changed without loss for one player. On domains Cl-1 and Cl-5, where fighting occurs and not all spots are fished, the perfect equilibrium is suboptimal and can be reformed.

[Table 4.3 about here]

Rule Configurations Two through Four

We now turn to rule configuration C2. In this rule configuration we replace the default authority rule by the rule that any player who first arrives at a fishing spot is permitted to fish at that spot for the day. The rule of "first in time, first in right" eliminates the possibility of fighting. The change in the game structure as a result of the change from Cl to C2 is drastic. As Figure 4.4 shows, all personal moves after the first two are truncated because the second player on a spot automatically moves away. This choice leads to Game 7.

Game 7

1 \ 2	travel to spot I	travel to spot II
travel to spot I	$v_I+v_{II}-3c)/2$ $(v_I+v_{II}-3c)/2$	v_I-c $v_{II}-c$
travel to spot II	$v_{II}-c$ v_I-c	$v_I+v_{II}-3c)/2$ $(v_I+v_{II}-3c)/2$

For this game, there are two physical domains, each with a unique perfect equilibrium.

[Figure 4.4 about here]

<u>Domain C2-1</u>. $v_I > v_{II} + c$.

On this domain travel to spot I is a dominant strategy for each player. An optimal assignment of fishing spots results (both spots are fished), but extra aggregate travel cost in amount c is incurred.

<u>Domain C2-2</u>. $v_I < v_{II} + c$.

On this domain the unique perfect equilibrium is completely mixed. The probability of travel to spot I is equal to $(v_I - v_{II} + c)/2c$, and the expected payoff to each player is

$$\frac{1}{4}\quad 3v_I+v_{II}-5c+\frac{(v_I-v_{II})(v_{II}-v_I-c)}{c}$$

This payoff is somewhat higher than in domain C2-1, but bounded above by vI-c.

[Figure 4.5 about here]

Notice that the strategic complexity of the decision lessens as the rules govern more choices. This is to be expected--any rule change that cuts down on strategic possibilities cuts down some of the game tree with it. (2 x 2 tic-tac-toe is much simpler than 3 x 3 tic-tac-toe.) One could even say that rules are a substitute for strategy. In cases where "smart" fishers obeying rule configuration Cl will not fight, even less "intelligent" fishers obeying rule configuration C2 will not fight.

We now turn to rule configuration C3. This rule configuration expands the "first in time, first in right" rule to include an option for a player to announce an intention to travel to a particular spot for a day. Once one player makes such an announcement, the other fisher must travel to the other spot.

The force of precommitment—like bidding in bridge or betting in poker—is to drive the fisher moving first to the best spot. But the fisher "going first" could be either one. Under this rule configuration each fisher can expect the payoff (vI + vII)/2 - c. The rule change reduces the strategic opportunities open to the players by increasing the choices that the rules govern. Alternatively, one could say that game C3 is simpler to play by virtue of the rule change.

Rule configuration C4 actually refers to a repeated situation to implement the rotation of spots. In this rule configuration each player agrees to alternate fishing spots in a coordinated manner. If the start of the rotation is unknown and determined randomly, however, then this rule configuration looks just like C3 in its first stage. Moreover, after sufficiently many repetitions, the rotation versus randomization effect will vanish between these two games. The average payoff per period will approach arbitrarily close to (vI + vII)/2 - c. This rule configuration represents the ultimate in rule expansion for these physical domains. Now all choices are rule-governed, and no strategic moves in this environment remain for the players. The game is gone.

Outcome Comparison

It is often useful or necessary to compare the outcomes of different rule configurations. Let f(C) denote the outcome of rational play under rule configuration C. When there is a unique perfect equilibrium, f(C) is a singleton; otherwise, it consists of the set of perfect equilibria. We say rule configurations C and C" are outcome-equivalent if f(C) = f(C'). In such cases one can say that the rule difference between the configurations C and C is inessential, because it makes no difference to the outcome of rational play. For instance, the rational outcome of tic-tac-toe is a draw, regardless of whether the player marking "x" or the player marking "o" moves first. Again, it makes no difference to the rational outcome of a secret ballot whether votes are cast on paper ballots or electronically. In the fishing-location assignment game, rule configurations Cl and C2 are not outcome-equivalent. Some potential rule configuration would be outcome-equivalent for some limited domains. This possibly motivates a brief discussion.

Definition. Rule Configurations C and C' are conditionally *outcome-equivalent* if on the domain D, f(C) = f(C').

If we were to examine a Rule Configuration C2', which kept the Position Rule of Cl (stronger fisher plays Position 1) and added the Authority Rule of C2 (first in time, first in right), then Cl and C2' would be conditionally equivalent. If one has prior knowledge of the physical domains affecting the payoff functions, then even this limited notion of rule equivalence can be quite useful.

A rule change that affects no change in outcome hardly can be called a reform. We call rule configuration C *a reform* of rule configuration C if and only if all players prefer f(C) to f(C). In other words, a reform leads to a strict Pareto improvement. By the same token we call C'a *welfare improvement* of C if the aggregate payoff at f(C') exceeds that at f(C). Clearly, a reform is a welfare improvement, but not necessarily the converse. Again, we can apply these terms both unconditionally and conditionally.[10] Consider physical domains Cl-5, where p = 1/2 and both fishers go to spot 1 and fight. This outcome is clearly suboptimal. In this case rule configuration C3 is a reform of rule configuration Cl:

$$(v_I + v_{II})/2 - c > (v_i - d)/2 - c.$$

Whether the players themselves will undertake a reform depends on the costs of transforming the rules themselves as well as more general costs of collective action (E. Ostrom 1990). If the costs of transforming the rules alone exceed the benefits of making the rule change, then players will continue to follow rules leading to "suboptimal" outcomes.

Summary

While the rule configurations that we have examined are extremely simple —containing primarily default rules—we can demonstrate that: (1) simple changes in rules can have a dramatic effect on the structure of a game and on equilibria and (2) an overt change in rules may NOT always produce a different equilibrium, at least in some physical domains. We consequently define outcome-equivalence and conditional outcome-equivalence as a means of evaluating whether a change of a rule configuration leads to a change in equilibria in all or a limited set of physical domains. Further, we define a rule reform to exist when all players prefer the equilibria produced by one rule configuration to those produced by another rule configuration and a welfare improvement to exist if the aggregate payoff of one rule configuration is greater than that of another.

The particular games we have examined are extremely simple, involving a two-fisher world and no threat of over-fishing. The structure of these games, however, as a first approximation to represent some of the strategic and deontic considerations related to international conflict over the use of contested waters, the open sea, Antarctica, or even outer space. When institutional rules are effectively matched to particular physical domains, it is possible to reform games with non-optimal equilibria into games with better equilibria.

Table 4.1. Logical Relationships among Physical Domains, Institutional Rules, and Outcomes

	Physical and Biological Domains	Institutional Rules	Outcomes
(1)	s	s	s
(2)	s	s	d
(3)	s	d	s
(4)	s	d	d
(5)	d	s	s
(6)	d	s	d
(7)	d	d	s
(8)	d	d	d

s = same
d = different

Table 4.2. Rule Configurations

	C1	C2	C3	C4
Authority Rules				
Default Authority Rule	1	0	0	0
First in time first in right (a)	0	1	0	0
First to announce first in right (b)	0	0	1	0
Prearranged Rotation (c)	0	0	0	1
Position Rules				
Default Position Rule	0	1	0	1
Stronger fisher plays Position 1 (d)	1	0	0	0
Position assigned randomly (e)	0	0	1	0
Default Boundary Rule	1	1	1	1
Default Aggregation Rule	1	1	1	1
Default Scope Rule	1	1	1	1
Default Information Rule	1	1	1	1
Default Payment Rule	1	1	1	1

(a) Any player who first arrives at fishing spot m is permitted to fish at spot m for the day; other players are forbidden to fish at spot m for the day.

(b) Any player who announces to other players a plan to fish in spot m for a day is permitted to fish there for a day; other players are forbidden to fish at spot m for the day.

(c) Players i and j rotate each day between spots m and n.

(d) Fisher who wins a fight (with probability p) plays Position 1.

(e) Positions are assigned by an equal chance move at the beginning of the sequence.

Table 4.3. Perfect Equilibrium Behavior, Rule Configuration C1

Domain	Both Fishers go to Better Spot and Fight	Better Fighter gets Better Spot
C1-1	X	
C1-2		X
C1-3		X
C1-4		X
C1-5	X	

Figure 4.1. Game According to Rule Configuration C1.

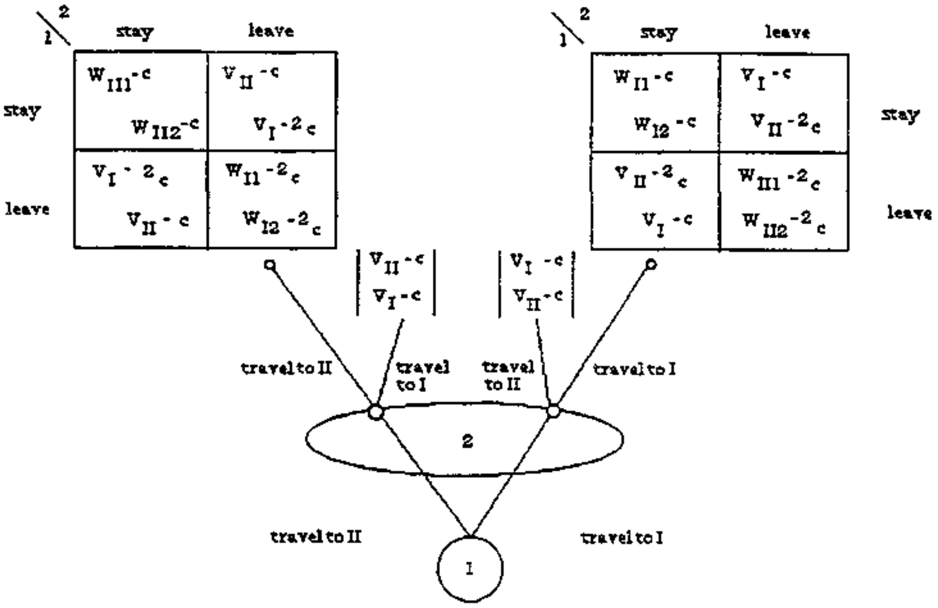


Figure 4.2. Willingness to Fight on Spot I (serious damage)

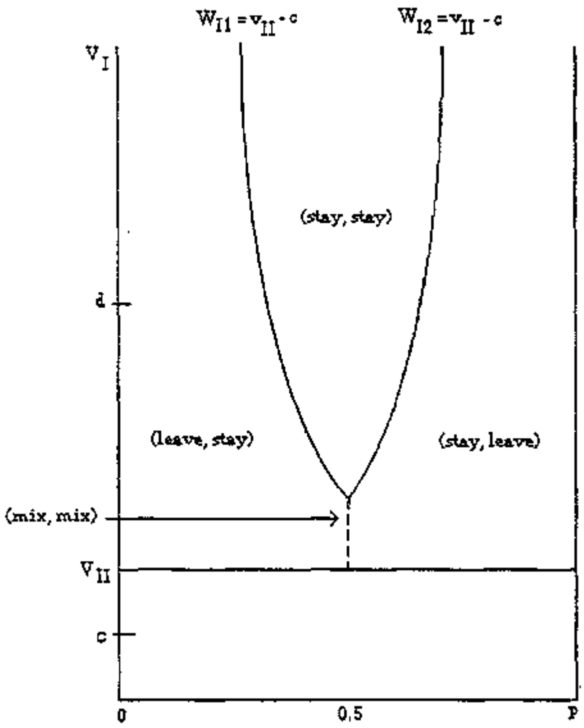


Figure 4.3. Willingness to Fight, Spot II (mild damage)

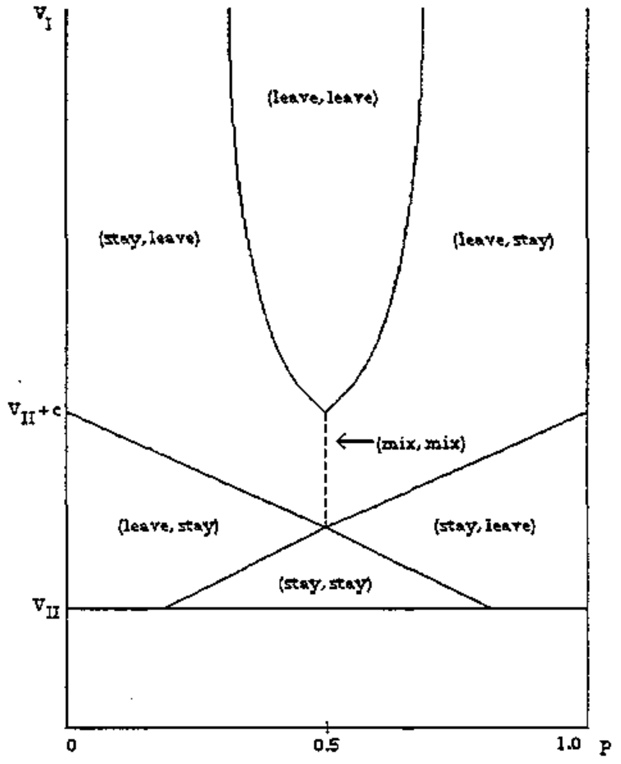


Figure 4.4. Extensive Game, Rule Configuration C2

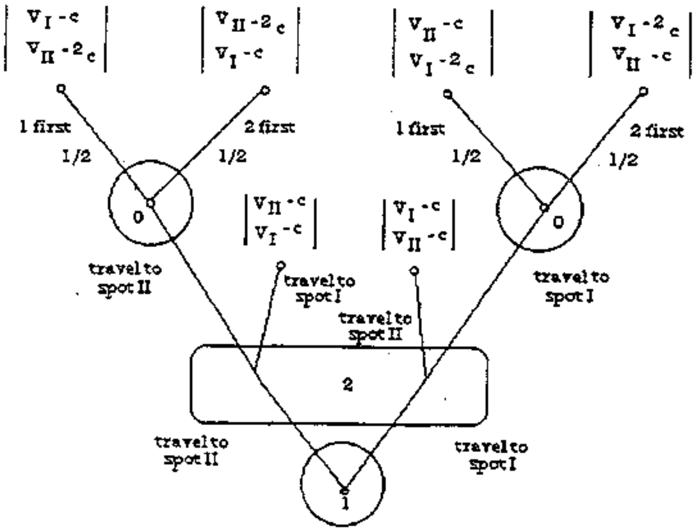
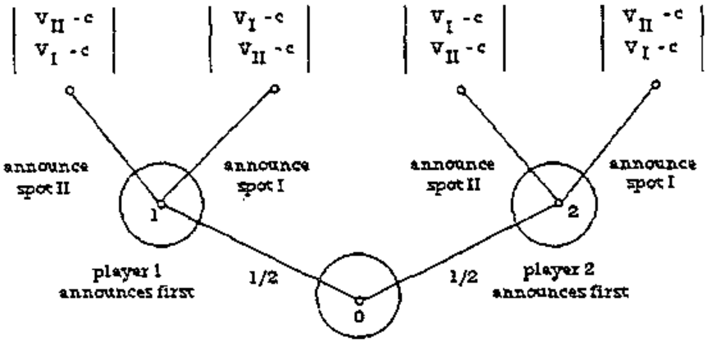


Figure 4.5. Extensive Game, Rule Configuration C3



Notes to Chapter 4

1. See 6. H. von Wright (1971), Explanation and Understanding, Ch. 2, for a discussion of nomological techniques; and the same author's Norms and Action, for a discussion of deontic techniques.

2. In this chapter, we do not attempt to include the third major underlying factors affecting the structure of a game, or an action situation, that of the structure of the community. Thus, the analysis presented here is relevant to situations where the structure of the community remains constant while both the physical and deontic world changes.

3. See, however, Plott and Meyer (1975) for an interesting paper describing the effect of several rule changes on the structure of a game. Shepsle and Weingast (1981a, 1981b) also explore similar questions.

4. The concept of a default rule emerged from a long series of discussions among William Blomquist, James Wunsch, and Elinor Ostrom as we attempted to develop a systematic method for describing naturally occurring rule systems. This concept was obviously influenced by experience in configuring computer systems that are set by the manufacturer at a series of default conditions that can be changed resulting in a large number of combinations. The common law of contracts, as well as the Uniform Commercial Code, provides a set of default provisions for courts to follow when specific contested contracts remain silent.

5. In many cases those directly involved recognize that violence is too costly and develop their own rule systems that are mutually agreed upon, to allocate rights and duties. For descriptions of situations where participants have crafted their own rules, see E. Ostrom (1988, forthcoming), Anderson and Hill (1975), Libecap (1978), Umbeck (1977, 1981).

6. See the very interesting issue of the Washington University Law Quarterly (Fall 1986) devoted to a symposium on "Time, Property Rights, and the Common Law." In particular, Richard A. Epstein (1986) discusses the effects of rules

of first possession in relationship to a variety of different kinds of situations. See, also, the perceptive papers by Haddock (1986) and by Barzel (1968, 1974).

7. First in time rules solve an "assignment problem" but may not solve a "rent-dissipation" problem (see Gardner, E. Ostrom, and Walker 1989; Haddock 1986; Clark 1980, Gordon 1954).

8. While the difference between a simple "first in time, first in right" rule and a "prior announcement rule" appears at first to be relatively trivial, it may make a considerable difference in the structure of a game and outcomes (as we show later in the paper). In any situation where getting to the location involves high costs, the capacity to register in a central location an intent to use significantly reduces transportation costs and the potential for violence stemming from these costs. Land registry offices in conjunction with homesteading are examples of highly formalized mechanisms related to "prior announcement rule."

9. The four authority rules just described are neither logically nor empirically exhaustive of the authority rules that fishers use. These four authority rules are classic examples of well known kinds of authority rules found in practice. In this initial, formal effort to model both the rules and the resultant games and outcomes, we wanted to: (1) keep the rule configurations as simple as possible, (2) use rules that are frequently used in other environments, and (3) illustrate the choice of rules with real examples. An extension of the work presented here would be to model the choice of institutional games. Shepsle and Weingast (1981as 48) envision the choice among institutional games as involving analysis where "it is necessary to model the equilibrium outcomes of these games under different assumptions. The choice among games is then seen as the choice among equilibria" (see also Shepsle and Weingast, 1981b; 516). The choice of games, however, always will be made from a subset of all possible games, rather than from the full set. While the set of rules structuring games may be finite, the set of possible

games that can be constructed from these rules approaches infinity (see Chomsky, 1980: 220).

10. These definitions suffice when f(C) is single-valued, as it is here. If one prefers to work with set-valued f(o), then the definitions can be extended appropriately. Thus, C is a welfare improvement over C if every member of f(C') has higher aggregate payoff than any member of f(C). When f(C') and f(C) are singletons, this definition reduces to the one in the text.