Chapter 3

PROPERTY RIGHTS, PUBLIC GOODS AND THE ENVIRONMENT

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Contents

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Abstract

We delineate the various ways in which rights to environmental and other resources can be assigned to individuals or groups. We then examine models of individual and group interactions, drawing out their implications for the ways in which resources will be utilized and managed under various rights assignments. Resources are classified into various groups (such as "collective" and "private") depending on the type of rights assignment that is most appropriate, and we critically examine situations in which it is claimed that certain combinations of rights and rules of behavior will lead to an "ideal" allocation of the associated resources. We argue that in all but a very limited set of circumstances, efficient allocations will require at the least some form of social intervention, and we discuss both formal and informal models of social organization toward this end. Various distortions are identified that may arise when incorrect assignments of rights are utilized. We discuss various practical ways of correcting for these distortions using instruments such as taxes, quotas, and markets for pollution permits.

Keywords

property rights, public goods, Coase theorem, open access, self-organizing systems, externalities

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1. Introduction

In discussions of environmental management, the view is sometimes taken that if we could get the assignment of property rights correct, the desired conservation policies could be achieved by parties exercising those rights. We discuss here the various ways in which rights to environmental resources could be assigned and the variety of social institutions that have been or could be created to enforce these rights. We will see that the appropriate rights scheme varies depending on the nature of the resource involved, and we will try to elucidate the factors that determine whether or not the position suggested in our opening sentence is justified.

At the outset, it should be clear that the assignment and enforcement of property rights is essential to facilitate any allocation of resources by private parties. Indeed, unless there is a proscription against theft, ownership has no real meaning and no one would pay anything for any valuable asset that could not be nailed down.

The assignment and enforcement of property rights is a way of institutionalizing ownership of resources. In capitalist societies it is implicitly assumed that the assignment of private rights is a good thing and further that the costs of enforcement (through a system of laws, police to monitor them and courts to settle disputes) are negligible compared to the benefits so derived. Socialist societies are not willing to go as far in assigning rights to individuals but rather seek to assign some of them to collectives (see below). However, economic analysis of either type of system still has generally ignored the costs of enforcement. We will see later that there are times when these costs should not be ignored, but defer such discussion until we have laid the appropriate framework.

2. Taxonomy of property rights[1]

There are at least two distinct dimensions on which property rights regimes may differ: (1) the scope of the exercising group and (2) the degree of control granted to the exercising group. In category (1) we will distinguish four levels: *private*, *collective*, *government*, *open*. A *private property right* is one that is exercised by a single individual. The right to one's own labor time is an example of this type. A *collective property right* is one exercised by some specific group (the collective). Examples of collectives are traditional fishing or herding cooperatives and homeowners' associations. When the collective is a political entity, we refer to the associated right as a *government property right*, where the entity could be anything from a county to a nation. Here, examples would be regional and national parks. When the collective is "all comers" we refer to the right as an *open right*. Examples here would be unregulated fisheries and open range.

Rights can involve varying degrees of control over the associated resource. We distinguish here between rights to *use* and rights to *regulate*. Use rights include *access* and *withdrawal*.

[1] The taxonomy adopted here is roughly that of Schlager and Ostrom (1992). Also, see that paper for references to the earlier literature.

Access: The right to enjoy or experience the resource but without changing it quantitatively or qualitatively.

Withdrawal: The right to diminish the resource in some specified quantitative or qualitative way.

As examples, a person who enters a national park has access but not withdrawal rights. By contrast, a person who enters a national forest with a cutting permit has both access and withdrawal rights (to a specified amount of firewood or timber).

Regulation rights include *management*, *exclusion*, and *alienation*.

Management: The right to transform the resource by making improvements or otherwise altering the nature of the resource and to determine how any associated benefits or costs are to be distributed.

Exclusion: The right to determine who will have what access or withdrawal rights, on what terms these rights will be granted, and how these rights may be transferred.

Alienation: The right to sell or lease either of the other regulation rights.

A complete rights regime for managing some resource must assign each of the five control rights to some individual or collective. In many practical cases, different control rights will be assigned to different collectives. For example, in the case of a condominium homeowners' association, access rights and that part of exclusion which deals with access are assigned to individual owners, whereas the remaining rights are exercised by the collective of owners (although in some cases, individual owners retain some of the regulation rights as well). We can complete any system of rights by using the natural convention that if some control right is not assigned, then it is automatically an open right. For example, in national forests access is treated as an open right whereas the other rights typically are exercised by the government. Of course, if a particular right is open, exclusion and alienation become meaningless with respect to that right.

In much of the sequel we will be concerned with the normative question of how to assign and exercise rights to environmental resources in an "optimal" way. We will see that the answer will differ from resource to resource and indeed that for some resources, there may be no optimal design. We begin with the natural benchmark of private property.

3. Scope and limitations of private property

A resource is private property if all of the rights with respect to that resource are assigned to an individual. For example, if I own my own home with no liens, I have the right to exclude (decide who may enter), I may make improvements at my own expense and I can sell whenever I want.[2] It has long been a tenet of capitalist economics that

[2] In reality, even here some rights are assigned to the state – the right to enter with a search warrant and the right of eminent domain. But we will ignore these exceptions in our discussions of private property.

for a large class of resources, private property is a good thing in that private property regimes facilitate an efficient allocation of resources through the use of markets. Since this is well trodden ground, we sketch only briefly the main argument.[3]

Establishment of private property rights is a necessary precursor to the use of markets and indeed is usually directly associated with the presence of market institutions. There are strong reasons why this should be so, as once the rights are in place there are incentives for individuals to create markets and under certain circumstances we know that markets are an efficient way of allocating resources. Let us see how this might work. Suppose that there are no enforced regulations on the disposal of household garbage. Then, ignoring the possibility of altruistic behavior, we would expect everyone to dump their garbage on someone else. And this outcome will likely be inefficient in that some people will have isolated sites where dumps would not have large disutility, whereas others will not. Now, once a right is established whereby I cannot dump on you without your permission, persons with isolated sites have incentives to offer dumping services for compensation from those with comparatively high disutility. Both parties are winners as long as the price is set between their relative disutilities, so economic efficiency is improved. As long as none of the parties involved have enough power to influence the market clearing price, the outcome will be an efficient allocation of garbage. In the parlance of economic theory, markets succeed in internalizing the *externality* created when I dump garbage on you without your permission. Not only has the private property right promoted efficient allocation but it has done so automatically, without the need for interference except for the enforcement of the right. This is the major virtue of the "invisible hand".

3.1. The problem of open access

The preceding example suggests more generally that whenever private property rights are not assigned, the associated resource necessarily must take on a "public" character, by which we mean that any individual's decision to use or degrade the item necessarily has repercussions on others. In such situations, the social benefit from individual consumption is necessarily different from the private benefit and we may expect that unregulated private decision making will mis-allocate the resource. The classic paradigm in the property rights literature arises from the use of open access rights to some natural resource. This situation and the difficulties it entails frequently are referred to as "the problem of the commons". We illustrate with the case of cattle grazing on a piece of open access land.

We assume a production function for beef: $y = f(a, K)$, where a represents the number of head of cattle and K for the acreage of the rangeland (other inputs are suppressed

[3] There is no attempt here to give a complete treatment of the "first theorem of welfare economics" as that would take us too far afield and there are many excellent treatments available. For a relatively nontechnical textbook treatment, see Varian (1978). The classic technical exposition is Debreu (1959). For a more complete exposition of the example used here, see Starrett (1988).

for simplicity). Ranchers will be indexed by i and we make the "common pool" assumption that all cattle put on the land will mingle in such a way that each gets its share of the fodder. Thus, if rancher i puts a_i cattle on the land and others put on a_{-i} (so $a = a_i + a_{-i}$), output to rancher i will be

$$\left(\frac{a_i}{a_i + a_{-i}}\right) f(a_i + a_{-i}, K).$$

We treat this range as small relative to the total cattle market so that prices can be treated as given, p_y for meat and p_c for cattle (alternatively we can think of this as a partial equilibrium analysis). Then, the first best use of the range will be determined by choosing the number of cattle to maximize profits: $p_y f(a, K) - p_c a$, so the optimal choice of a must satisfy:

$$p_y \frac{\partial f}{\partial a} = p_c,$$

that is, cattle should be chosen so that the price equals the value of the marginal product (VMP) in producing beef.

However, if there are many users of the common, rancher i will choose the size of his herd to maximize:

$$p_y \left(\frac{a_i}{a_i + a_{-i}}\right) f(a_i + a_{-i}, K) - p_c a_i$$

which generates the following first order condition for choice of a_i:

$$\left[\frac{a_{-i}}{a}\right] \frac{p_y f(a, K)}{a} + \left[\frac{a_i}{a}\right] \frac{p_y \partial f(a, K)}{\partial a} = p_c.$$

Thus, we see that the rancher will choose his herd so that the price of cattle is equal to a *weighted average* of the marginal and average product of the extra cow. For added simplicity let us assume that each rancher is small relative to the whole so that the first term in square brackets above is approximately equal to one and the second approximately equal to zero. (Note that the same analysis will apply if the rancher ignores the effect that the last cow he adds will have on the grazing opportunities of his intra-marginal herd.) Then our rancher will add cows until the value of the *average product* (VAP) of the extra cow is equal to its price.[4]

[4] More generally, we can show that if all ranchers are identical then the expected equilibrium outcome will be one in which all ranchers graze the same number of cows and that the degree of overuse on the common will be increasing in the number of users. For more on the concept of equilibrium involved here and the general presumption of inefficient outcomes, see Section 5.

So we see that open access will lead to distortions in behavior to the extent that the average and marginal products of cows differ on the common. If there were no crowding out effect so that the marginal product was independent of the number of cows, then of course marginal and average products would be the same and there would be no distortion. However, once the range land starts to fill up, marginal product will begin to fall and therefore will be below the average product. At that point open access will lead to overgrazing as each rancher adds cows beyond the point where VMP equals price, to the point where VAP equals price. In fact the VMP might actually be negative at the equilibrium point.

The distortion can be explained in terms of externalities; when one rancher adds a cow, there is less fodder available to others' cows so that their profits are marginally reduced. Since the extra cow earns its owner VAP but only contributes VMP to the total, this external cost is measured as VAP minus VMP. (As an exercise, the reader might derive this formula using calculus.) Because this extra social cost is ignored, the rancher adds cows beyond the socially optimal holding capacity and the common is overgrazed.

As with the case of garbage, the introduction of private property rights and associated markets can be used to internalize this externality. Here the land is being treated as a free good under open access, whereas it has scarcity value (due to the crowding out). If the land is treated as private property[5] and traded on markets this scarcity value will be reflected in land rent and the rancher will either have to pay this rent to expand his herd or suffer himself the loss in marginal product of adding cattle to fixed land. Without doing a full analysis, we can argue that the rent will exactly internalize our externality. Assuming that there are no other fixed factors to producing beef,[6] we expect the production function to be constant returns to scale; that is doubling the land and doubling the cows should serve to double the beef. For such functions it is well known that the competitive value of the factors of production exactly exhausts the value of final product. Here this means that the value of the land as input to producing beef plus the value of the cows in producing beef should equal the total value of the beef. It follows that the value of the land per cow employed is equal to VAP minus VMP. Consequently if a rancher is willing to rent the land needed for an extra cow, he must be willing to pay the externality cost, now reflected in the scarcity rent on land. Alternatively, if he adds an extra cow to a fixed piece of land he absorbs the externality cost. On the margin, he will be indifferent between these two options and an efficient use of the land will result.

3.2. Potential conflict with equity

Of course, we know there are limitations to market efficiency, and these translate naturally to shortcomings of private property rights. We take up a philosophical objection

[5] In this case, there will be some costs of exclusion (e.g., building fences) associated with the enforcement of private property rights. These are ignored here but we will have more to say about this in the sequel.

[6] If there are other factors of production and they are priced correctly the same analysis will apply.

first and turn to intrinsic difficulties in the next section. The exclusive use of private property rights has implications for the distribution of income. Indeed, the most common argument in favor of socialism (in which some subset of resources is not assigned as private property, but rather owned collectively) claims that capitalism generates an allocation of resources that is inequitable, in that some agents wind up commanding a disproportionate share of resources. One might think that it would be possible to achieve any desired distribution simply by rearranging property rights. In principle that is true, but implementation would involve some degree of slavery as we might have to assign a talented person's labor time to someone with less talent. Assuming we rule out slavery, as most societies now do, we can make the income distribution more even only by use of taxes and transfers. There is a large literature on the design of tax/transfer systems with the aim of creating ones that do not distort economic incentives.[7] (Note that even if we allowed slavery, there would be incentive problems in eliciting effort once we take into account the costs of monitoring.) Most economists believe that such 'incentive compatible' schemes (if possible at all) are impractical so that any attempt to redistribute income must entail some loss of economic efficiency.[8]

This conflict between egalitarian distribution and efficient allocation through the market system is an old problem without a satisfactory solution.[9] The presence of this conflict is the justification for the socialist position that some resources should be treated as collectively owned even when it would be possible to assign and enforce private property rights. But even without the socialist's view, there are more fundamental impediments to the use of private property rights, as we will see in the next section.

4. Publicness and the need for collective rights

As we saw in the previous section, the private assignment of property rights can serve to internalize what would otherwise be damaging externalities. Unfortunately, for many goods and services and especially for many environmental resources it is difficult to make such assignments effective. The issues here are generally well understood and there are many excellent textbook expositions.[10] Therefore, we will confine ourselves here to a brief summary together with references to that literature.

[7] For a discussion of various types of taxes and their distortions, see chapters in Handbook of Public Economics, Vol. 1 (1987), or a text such as Boadway and Wildasin (1984), Atkinson and Stiglitz (1980), or Laffont (1989).

[8] However, we will see later that it may sometimes be possible in the context of environmental resources to use the assignment of rights in such a way as to affect the distribution of income without incurring distorting incentive effects.

[9] There is, however, a school of thought which I will refer to as the "entitlements" school that has it that people are entitled to what they start with and therefore, that the resulting market distribution is in fact equitable. For an exposition of this view, see Nozick (1974).

[10] See, for example, Baumol and Oates (1988), Boadway and Wildasin (1984) or Oakland (1987).

The biggest impediment to use of markets to allocate environmental resources is *nonappropriability* – namely, the difficulty or impossibility of enforcing a private property right. A pure example of such a resource is "clean air". It is not possible to assign an individual the right to clean air over his property since there is no practical way to prevent that air from mingling with "dirty" air coming from elsewhere. Or alternatively, we might say that the costs of enforcing a private right (by erecting barriers) is prohibitive. Other environmental resources with similar character include fish in the ocean, greenhouse gas concentrations and lake water quality. Even when a property right can be enforced it still might not be desirable if the costs of enforcement (which as we have said are usually ignored) are too high. For example, as indicated earlier, grazing land can be treated as private property only at the cost of building fences or walls. When the density of use is sufficiently small, the benefits of efficiency may not be worth this cost so we may prefer "open access".

Even when exclusion is costlessly possible, it may not always be desirable from an efficiency standpoint. This happens for resources that have an element of *nonrivalry*. A resource possesses some degree of nonrivalry if my use of it does not completely preclude your use. As an example of pure nonrivalry, consider radio or television signals.[11] My use of the signal to obtain reception does not in any way preclude your using the same signal. In this case, we can in principle exclude some users at a finite cost (through the use of scramblers) but it is inefficient to do so; once the signal is sent (and the associated costs sunk) the greatest benefit will be derived from allowing all potential users free access. Another commodity with nearly the same character is information. Once it is produced the costs of dissemination are minimal so that efficient management would dictate free access. Notice that if we do choose not to exclude then the associated commodity takes on the same public character as we identify with the inherently nonappropriable goods. Goods, services and resources that are either nonappropriable or nonrival we label as *collective* – items in this class cannot be efficiently allocated through the use of unregulated private property rights. The extreme examples in this class possess both properties. "National defense" and "ozone protection" are cases in point. In both cases, it is not possible to exclude citizens from the benefits nor is their a cost of allowing additional users (or enjoyers). Our concept of collectiveness is intentionally broad so as to encompass the various types of pure, impure and local public goods introduced in the economics literature.

Although we will treat them relatively symmetrically here, there are some important distinctions between the two types of collectiveness. This is because while exclusion is a binary concept (either you do or you do not, the decision generally depending on the costs of exclusion compared to potential benefits), rivalry is a matter of degree. The lanes of a highway can be either completely nonrival (when few cars are present) or completely rival (when there is queuing to get on) or anything in between. These

[11] The two-way dichotomy involving appropriability and rivalry is widely attributed to Richard Musgrave. See Musgrave (1959).

distinctions play important roles in determining the optimal allocation of associated resources, and are central to the theory of local public goods, but further discussion is beyond the scope of this chapter.[12]

"Collectiveness" does not entirely preclude the use of markets but does imply that if employed they will work inefficiently at best. There are two ways in which markets might be used in this context – for nonrival goods, we can exclude and force agents to pay for use or, for nonexcludable goods, we can allow agents to contract for use but not exclude. As an example of the first type we may use patents to exclude potential users from free access to information, as a way of providing incentives for the production of such information. But we would be even better off if we could provide those incentives in another way, since the patent royalty will deter agents whose potential benefit, though positive, falls short of the royalty. As an example of the second type, suppose we sell community safety through the market. That is we allow citizens individually to purchase police time for patrolling the town streets. It is possible that there would be some purchases on this market but we argue that these will be lower than desirable for the overall social good; when any particular citizen purchases police time, most of the benefits go to others (referred to as "free riders" in the literature) who will benefit equally from the police presence. Here (in contrast to the case of privately divisible goods such as bread or steel) the private benefit from purchase is lower than the social benefit. Since market price can only reflect the private benefit, police protection will be underprovided in this case compared to the first best. The problem here again can be viewed in terms of externalities: when one agent purchases services he confers external benefits (or costs) on others who will also be affected. For further discussion of the voluntary (private) provision of public goods, see Chapter 4 (by Baland and Platteau).[13]

Thus, we see that when the resource in question is collective in nature we will have to assign at least some of the rights collectively if we seek to achieve optimal management. Our problem becomes one of determining the appropriate collective group for each type of control rights and to design procedures whereby these groups will be induced to make the right decisions.[14]

5. Outcomes under decentralized decision making

When private property rights are appropriate and are properly defined and enforced, we have seen that decentralized decision making through the use of markets can generate

[12] For surveys of the theory of local public goods, see Rubinfeld (1987), Starrett (1988, Chapters 5 and 11), or Cornes and Sandler (1996).

[13] See also Oakland (1987), and Inman (1987) for additional perspectives on market provision of collective goods.

[14] For general discussions of the appropriate assignment of rights see Barzel (1989), Bromley (1991), and North (1990).

an efficient allocation of resources. Decentralization has the desirable features that implementation requires little or no communication and coordination among the agents. Here we ask what we should expect from decentralized behavior in more general situations where private property rights are either undesirable or unenforceable. Throughout the sequel we will assume that agents have *complete information* about the allocation situation at hand. In particular they know the payoff relevant outcomes for them as a function of the actions taken by all participants, and they observe those actions, at least after the fact.[15] Given this context, we must determine how agents will act when they know their actions will have observed effects on third parties. And the answer is very likely to depend on context: for example, if the agents interact with each other more than once, each will surely realize that actions taken today will be observed by others and consequently may well influence subsequent behavior. But before discussing such complications let us consider the case of one-time interaction.

5.1. Static interaction

Assume first that we are in a static (timeless) world where agents come together only once and all relevant outcomes are determined by their simultaneous actions. Even here, there is no single behavior that will be convincing in all situations, especially when there are small numbers of players (as, for example, in a product duopoly) who will be acutely aware of their strategic interaction. We start with an example which is fairly representative of situations with "free rider" incentives, and where the strategic issues are easily resolved. Suppose there are two firms (I, II) both of whom use a common lake. Each uses lake water as an input and also possibly as a repository for waste. For simplicity we assume the firms are identical and that the only strategic choice they have is whether to dump effluent into the lake or treat their waste. Assume the following per firm costs and benefits:

Cost of treatment:	6,
Benefits from clean water:	8,
Benefits if one firm dumps:	5,
Benefits if both firms dump:	0.

We can represent this strategic situation in a two by two matrix "game form":

		Firm II	
		treat	dump
Firm I	treat	(2, 2)	(−1, 5)
	dump	(5, −1)	(0, 0)

[15] Note that without this assumption it would be impossible to predict an outcome without specifying exactly what each agent knows and what she believes about things she does not know.

There are four possible combinations of strategies (each firm can treat or dump) and the table numbers indicate the net payoffs to (firm I, firm II) of the associated strategies. For example, if both firms treat, they each get benefits of 8 and pay treatment costs of 6 for net return of 2. Or if firm I treats but firm II dumps, they each get benefits of 5 but firm I pays costs 6, so the net returns are $(-1, 5)$, etc.[16]

Note that regardless of what firm I is expected to do firm II wants to dump (and vice versa): if firm I treats, firm II will get 5 rather than 2 by dumping and if firm I dumps he gets 0 rather than -1 by dumping. The incentive to "free ride" is dominant and in the absence of communication we should certainly expect both firms to dump. As a consequence they will reach an inefficient solution since they would be better off coordinating on a joint treatment strategy. Unfortunately, many environmental interaction situations have this property that free riding is a dominant strategy so we should not be surprised when we observe excessive pollution in decentralized, unregulated situations.

Of course, not all games have this "dominant strategy" structure. For example, in the grazing model presented earlier, one rancher's decision on how many cows to graze surely will depend on the numbers grazed by others. But in such somewhat more complicated situations it still may be reasonable to assume that all agents take as given the behavior of others and make their own choices to optimize against those expected behaviors. The corresponding outcome of decentralized decision making is a set of behaviors such that each agent's choices are optimal for him, taking as given the corresponding choices of others. In game theory we refer to these behaviors as *Nash behavior* and the corresponding outcome as *Nash equilibrium.* This view of behavior and the associated concept of Nash equilibrium seems the most plausible outcome in many static situations where there are relatively large numbers of players and communication is difficult or impossible.[17] Recall that we already employed it informally in discussion the problem of open access where we showed that it led to an inefficient outcome. Now, we claim a general presumption of inefficiency; namely, we argue that in any situation where agents' choices affect each other's payoffs in significant ways, the Nash outcome is almost certain to be inefficient from the point of view of the group as a whole.

Suppose that we are in a general situation in which payoffs of the various agents depend on actions they all take. Let a^i stand for the (vector) of decision variables available to agent i. To the extent that agents face constraints, we assume that they can be solved for a dependent set as functions of some independent subset, and that a^i represents the independent subset. The matrix of all actions will be simply denoted a (without a superscript). Further, the notation (a^i, b^{-i}) will mean the configuration in which agent i plays from configuration a whereas everyone else plays from b. Let $P^i(a)$ stand for the

[16] The reader will note that the payoff structure here is the same as that of the famous "prisoner's dilemma" game wherein two suspects would be best off if they kept their mouths shut, but each finds it a dominant strategy to implicate the other. Many games involving economic externalities have this same structure.

[17] However, the Nash assumption can be criticized on a number of grounds. For example, we can see that it is always disconfirmed out of equilibrium. For further discussion of this assumption and possible alternatives, see Fudenberg and Tirole (1991, Chapters 1 and 2).

objective function of agent i. Now a^* will be an equilibrium outcome for the group if each finds it best to use her a^* decision as long as she expects everyone else to do so as well; that is:

$$\text{for all } i, \quad P^i(a^*) \geqslant P^i(a^i, a^{*-i}), \text{ for all feasible choices } a^i.$$

We now argue that equilibrium in this context will generically be nonoptimal from the point of view of the group as a whole. This conclusion will hold no matter how we choose to weight individual payoffs in defining the group objective. Suppose we assign weights w_j and consider the social objective $W(a) = \sum_j w_j P^j(a)$. Thinking of a^i as one dimensional, we can define its marginal social benefit and marginal private benefit as

$$MSB^i(a) = \sum_j w_j \frac{\partial P^j}{\partial a^i},$$

$$MPB^i(a) = \frac{\partial P^i}{\partial a^i}.$$

Now, by the definition of Nash equilibrium (a^*), $MPB^i(a^*) = 0$ so

$$MSB^i(a^*) = \sum_{j \neq i} w_j \frac{\partial P^j}{\partial a^i}.$$

Thus, as long as the interdependences are generic, we expect to find the MSB's not equal to zero at equilibrium so the group can be made better off through marginal changes in private choice variables. Further, we can measure the marginal external benefit of choice a^i as $MSB^i(a) - MPB^i(a)$.

5.2. Repeated interactions through time

Let us now generalize to contexts where agents interact with each other on an ongoing basis. This is typical of many environmental situations where groups of people use the same grazing land, forest resources, water sources, and the like. It seems likely that behaviors might be different in this situation than with static interaction. In particular, agents might be deterred from "antisocial" behavior by the fact that it will be observed (at least after the fact) by others and might lead to retaliation.[18] Here, we examine the possibilities in the special case where the same "static interaction" is repeated by the

[18] The intuition here is quite old and not easily attributable. Indeed, the formalizations are frequently referred to as "folk theorems". See Friedman (1971) and Axlerod (1984) for good expositions.

same group of players a specified number of times (which might be finite or infinite).[19] In the game theory literature from which we draw, the static interaction is referred to as the *stage game*, the strategic situation defined by an infinite number of repetitions as the *supergame*, and the remaining opportunities for interaction after a certain date is reached as the *continuation game* from that date. To simplify further we assume that there is a unique Nash equilibrium (a^*) in the stage game. Note that this is true in both the examples we gave above.

In what follows it is critical what agents are able to observe and how they use that information. Here we assume that agent actions are observable to all after the fact and that agents will consider conditioning future choices on what they have observed. Note that these assumptions are conducive to generating the modified behavior suggested above, and indeed that if actions are completely unobservable it is hard to see how the fact of repetition alone would make any difference to behavior.[20] Let h_t represent the history of play up to date t. For example, in the water resource game above, the history would be a recording for each player as to whether or not he treated his waste in each preceding period, and in the open access range, the number of cows each rancher grazed in each preceding period. Then, a strategy for player i in period t is a function that maps each potentially observed history into a current action. We represent this function as $a_t^i = \sigma_t^i(h_t)$. An example of a strategy in the water resource game is "tit for tat": namely play today exactly as your opponent played yesterday – so if the other firm treated last period, you treat now, but if he dumped, you dump now. Note that for that particular strategy, the history before yesterday is ignored and indeed we do not require that all potential information be used in determining strategy.

We assume that agents value each continuation game as the discounted sum of payoffs from the associated series of stage games using a constant discount factor δ, that is,

$$V_t^i = \sum_{\tau=t}^{T} \delta^{\tau-t} P^i\big(\sigma_\tau(h_\tau)\big),$$

where V represents the continuation value and T stands for the time horizon (date at which the last stage game is played). It seems reasonable to require that agents act in any continuation game just as they would in a static game; therefore we require of an equilibrium sequence of actions that it constitute a Nash equilibrium in every continuation game entered. This is a special case of the *subgame perfect equilibrium*

[19] For a discussion of bargaining models with other structures of ongoing interaction, see Fudenberg and Tirole (1991) or Moulin (1986).

[20] Actually, even if individual actions are unobservable, agents may be able to infer something about such actions from observation of aggregates. For example in our water resource model, each agent can tell what his opponent did simply by observing the quality of lake water. When commonly observed variables can be used to identify private behavior, the results reported here will carry over with only slight modification [see Fudenberg and Tirole (1991, Chapter 5)]. Note that such identification is likely to be easiest with a small number of players.

for general sequential games. We are interested in determining what outcomes could be observed that are subgame perfect equilibria.

5.2.1. Finitely repeated games

Suppose first that T is finite; that is there is a date where it is known that the strategic interaction will end. For such games, subgame perfect equilibria can be determined by backward induction. Namely we can determine how the last stage game will be played. Knowing this, we can back up one period and determine how the continuation payoffs will depend on actions in that period, solve for the Nash equilibrium in that game and continue backward to the present. From this, we can show the somewhat surprising outcome that there is little scope for generating cooperation in finitely repeated games. To see this, observe that since the stage game is played in the last period continuation, equilibrium requires that all agents play according to a^*. But then, in the preceding period, continuation payoffs are just the discounted constant value of a^* plus the values of the current stage game. Consequently, subgame perfection requires that a^* be played in the penultimate period as well. Continuing the backward induction, we find that a^* must be played in all previous periods as well and there is no scope for cooperation at all.[21]

Many people find this conclusion counterintuitive. Namely it seems that if there are many periods to go, agents would want to play in a way that encourages cooperation, at least for a while. Further, when games of this type are simulated experimentally, players generally are observed to cooperate in the early stages when there are still many periods remaining. These considerations have led some to question subgame perfection and the concept of individual rationality that lies behind it. The interested reader is referred to game theory texts such as Fudenberg and Tirole (1991), as further discussion is beyond the scope of this chapter.

5.2.2. Infinitely repeated games

Part of the problem with the finitely repeated structure may be that in most real life situations there is no obvious last period of interaction, even though all agents know that the relationships will end at some unspecified date in the future. Consequently, use of an infinite horizon ($T = \infty$) may be a better approximation to the strategic situation that agents feel they face. With an infinite horizon, backward induction is no longer

[21] This rather severe conclusion does depend critically on our restriction to subgame perfect equilibria and the assumption that our stage game has a unique Nash equilibrium. If there are ways of punishing agents and thereby holding them to utilities below what they would get at a^*, these can be used to induce cooperative behavior in a Nash equilibrium of the finitely repeated game. However, this outcome cannot be subgame perfect [see Benoit and Krishna (1987)]. Also if there are multiple static Nash equilibria, the opportunity to switch among them can induce some degree of cooperation even in subgame perfect equilibria [see Benoit and Krishna (1985)].

available and we must find other ways of solving the game. And as we shall see, the outcomes can be quite different. Indeed, we will show informally that any stage game outcome that gives agents at least as much as they get from a^* can be supported as a subgame perfect outcome in the supergame if the discount factor is sufficiently high (that is the discount rate is sufficiently low, indicating that agents are relatively patient).

It is important to note first that even here, subgame perfection does not rule out the noncooperative outcome. Namely, the strategy: "play according to a^* in every period no matter what you observe" is always subgame perfect. The logic here is just as it was in the finite horizon case. If I enter a continuation game with the belief that everybody will play according to a^* in the future regardless of what I do now, then I will want to act just as if I were in a static stage game and will want to play according to a^* now.

What is different now is that many other outcomes are possible as well, at least when the discount factor is relatively high. To see this, let us see what would be required to support an outcome in the stage game with payoffs $v = P(a^v) \geqslant P(a^*)$ where a^v is the action that generates payoffs v. The idea is to employ the following punishment strategies: in any continuation game all agents will play according to actions a^v as long as everyone has played that way in all previous stage games, but will "punish" by playing according to a^* if any agent has played anything other than a^v in any previous stage game. Clearly if these strategies are consistently played, the outcome will be that payoffs v are realized in every period, so we want to know when these "trigger" strategies constitute a subgame perfect equilibrium.

With the trigger strategies, there are only two possible continuation games that can be entered, depending on whether or not someone has previously "defected". In the case where someone has defected, all expect play according to a^* subsequently and we have already seen that "a^* forever" is subgame perfect in that situation. Consider now the continuation wherein no one has defected heretofore. Let us see whether agent i will want to deviate from the cooperative strategy. If she chooses to deviate, she will play her best response to the cooperative strategy a^{v-i} from others, yielding for her a payoff w^i. For example, in our water resource game, the best response when your opponent treats is to dump and the corresponding payoff will be 5. Consequently, since she knows that after deviation, a^* will be played, we find:[22]

$$\text{value of deviation} = w^i + \sum_{t=1}^{\infty} \delta^t p^{*i} = w^i + \left[\frac{\delta}{1-\delta}\right] p^{*i}.$$

Therefore, the trigger strategies will be subgame perfect as long as the value of "cooperation" which is $v^i/(1-\delta)$ is at least as large as the value of deviation, namely if

$$v^i \geqslant (1-\delta) w^i + \delta p^{*i}, \quad \text{or} \quad \delta \geqslant \frac{w^i - v^i}{w^i - p^{*i}}.$$

[22] Since this game has a "time stationary" structure (continuation payoffs depend only on past history and not on calendar date), the choice of current date is arbitrary and we start from date zero.

So we see that if the discount factor is sufficiently large, the trigger strategies are subgame perfect and the stage game payoff v is supported as a subgame perfect equilibrium. For example, in the water resources game, we can support the cooperative play of always treating waste (yielding $V = (2, 2)$) as long as the discount factor is at least as large as $(5-2)/5 = 0.6$. Equivalently the corresponding discount rate would have to be less than or equal to 66%, a weak requirement!

Thus, we see that situations with repeated interactions give groups of agents an opportunity to foster cooperative behavior without explicitly entering into binding contracts. However, it would be wrong to say that efficient outcomes are being generated here by strictly decentralized behavior. Before these methods will work, there must be some common agreement on what it is we are trying to achieve (which V) and a common understanding of how sanctions will be used. In our simplified water resources model there was only one efficient choice, but generally we expect an entire "Pareto frontier" to choose from and resolving on a particular element requires reconciling preference differences. For example, in the grazing example, the surplus can be distributed in many ways determined by the numbers of cows assigned to a particular herdsman, and this allocation must be agreed to before any cooperative behavior will be enforceable. Further, the agreement on when and how to punish must be part of the social norms mutually accepted by the group. Thus, it is hard to see how cooperative behavior can be generated without substantial communication and bargaining. We turn next to an examination of what can be achieved when such interaction is allowed.

6. The Coase theorem and limitations

There is an old argument in the literature that as long as (1) property rights are assigned and enforced in an exhaustive (complete) way, (2) there is free and costless communication among agents, and (3) the control rules allow for bargaining among the collective of all affected parties, this collective will always reach an outcome through bargaining that is Pareto efficient. A stronger version of this "theorem" would have it that the allocation outcome reached is independent of how the rights are assigned. This second version generally is not true unless income effects are negligible since changing the assignment of property rights will change the distribution of income and, if preferences differ among consumers, also change the demands for goods and services. However, the first version may still be true. If it is, we could say that there is something like the invisible hand for collective property rights.

The simplest argument in support of the Coase theorem goes as follows.[23] Suppose an allocation has been proposed that is Pareto inefficient; that is, there is a change in

[23] This argument was first espoused by Coase (1960). However, even then he was aware of the fact that its force would be mitigated by the presence of transactions costs (see below). There are many general discussions of the Coase theorem and limitations. See, for example, Alchian and Demsetz (1973), Cooter (1987), Hoffman and Spitzer (1982) and Hurwicz (1995).

the allocation that will make at least one member of the collective better off and no one worse off. Then, if the parties who would be made better off proposed making this change, all rational parties should accept. This argument is independent of who has rights. If I have the right to pollute but am polluting to such a high level that you would pay more than it matters to me to get the level reduced, then you pay, but we are both better off. Alternatively, if you had the right to clean air, I wind up paying to pollute up to the level where my cost is worth marginally more than the extra pollution damage. In either case, we would continue to bargain until an efficient point is reached where the marginal benefit of extra pollution to the polluter is exactly offset by the marginal costs to pollutee. We already made this argument for the case of physical garbage but it should work just as well for collective goods as long as all affected parties are actively involved.

Although this argument sounds reasonable it involves many pitfalls and considerable care is required to specify precisely the conditions under which it is correct. Indeed, we believe that it is quite difficult to state and prove a "Coase theorem" precisely. Here we will confine ourselves to a discussion of necessary conditions for its validity.

6.1. Costless communications and implementation

We have already seen that unrestricted communication among the agents is essential to an efficient outcome. In situations with static interaction we argued that uncoordinated behavior would almost certainly lead to inefficient outcomes. And even in situations of repeated interaction some coordination on the desired outcome and punishment strategies would be required in order to achieve efficiency.

But it is not enough that agents can communicate freely – this communication and any associated rules for enforcement and implementation must also be costless. When there are small numbers, this assumption may be pretty reasonable, but it becomes less so as the numbers increase. The presence of nonnegligible transactions costs has independent negative implications for the Coase theorem. To illustrate, consider the following example involving a flood control project. A dam can be built for $10M which will provide $9M in benefits to a small group of people. The dam is to be paid for by taxing 10M people $1 each. This project clearly is Pareto inefficient since each of the taxpayers would be better off canceling the tax and paying $.91 to the benefitting group, an offer that group should accept since it provides them with $9.1M in benefits. But will this bargain be struck? Can the amorphous group of taxpayers coordinate? And even if they could would it be worth their effort given that each only avoids a $1 liability? It seems clear that if the costs imposed are sufficiently small and the numbers involved sufficiently large we will not see such outcomes due to the fact that transactions costs, though small, are not negligible. Indeed, projects of this type (sometimes referred to as "porkbarrel" projects) wherein benefits go to a relatively small group with costs being paid out of general revenue are a staple of government budgeting in much of the world. Note that the nature of property rights does matter now and will influence the outcome:

if taxpayers have the right to refuse the dam, and the developer is thus forced to make his case, the project will fail.

Similar reasoning suggests that bargaining alone will not "solve" the problem of open access. Suppose that there are many ranchers that graze their cattle on an unfenced piece of land. Then in the absence of bargaining, we saw that each will graze too many cattle since the social cost of an extra cow is imposed mostly on other ranchers (whose cows have less feed available). However, if all the ranchers get together, they should agree to a bargain wherein each reduces his herd by a small amount to the point where the marginal social cost imposed equals the marginal private benefit. But if there are large numbers involved, coordinating on this strategy and monitoring to enforce it may be more trouble than it is worth. Indeed, there is empirical evidence from studies of traditional societies that efficient management of common property is generally achieved only when the numbers are relatively small, and not always even then.[24]

6.2. *Commitment requirement*

Further, agreements must be enforceable in the sense already articulated in section 1. In the context of bargaining, this means that agreements must be observable to an enforcing party that can guarantee compliance. Without such assurance, I could take your money, agreeing to cut my pollution, and then renege; and you, anticipating this, would not pay.

There are differences of opinion in the literature as to what is allowable as part of a Coasian bargain. One view would have it that any arrangements for compliance and enforcement must be thought of as "outside" the bargain. Under this view, free riding on agreements is relatively easy and it must be left to mechanism design to make agreements incentive compatible. This is roughly the view taken by Baliga and Maskin in Chapter 7 (Mechanism Design for the Environment).

Here we take the view that Coasian bargains take place in the context of a social contract and can take advantage of its rules and regulations. However, we still need to take account of the limitations of these rules. Generally society imposes some limits on the type and character of agreements that are enforceable. For example, if a steel mill signs an agreement not to emit smoke from its stacks, there is no practical way to ensure that smoke is not emitted – the best that can be done is to impose some kind of sanction if and when smoke is emitted.

Once we recognize these restrictions we must require that agreements reached be "self enforcing" in that participants would prefer to remain in the agreement rather than revert to some fallback wherein they accept whatever sanctions are available. Such requirements are formalized in cooperative game theory by requiring that bargaining outcomes be *core allocations*. Informally, an allocation is in the core only if it gives

[24] For a discussion of institutional arrangements for handling the problem of open access, and examples of success and failure, see Schotter (1981), Martin (1989), Eggertsson (1990), Ostrom (1990), North (1990), and Hanna, Folke and Mäler (1996). Also for a report on outcomes from experimental design, see Ostrom (1999).

every *subcoalition* (subset of the whole group) of the society at least as much as they could guarantee themselves by "going it alone" – that is by withdrawing from the larger group, accepting whatever sanctions the rest of society can impose, and optimizing internally subject to those restrictions.

It should be clear that the limits to bargains imposed by restricting to the core will depend on what kind of sanctions are allowed – if we could throw all deviants in jail for life and strip them of all resources the restrictions would not bind at all. And while such draconian measures are unreasonable, we saw that something similar could be achieved in situations where the bargainers deal with one another on an ongoing basis. However, when sanctions are effectively limited, we will argue that restrictions to core allocations may preclude efficient bargains and further that the way in which property rights are assigned can be crucial to enforcing the efficient bargain.

These facts were first elucidated in the "garbage game" of Shapley and Shubik.[25] Here we modify this game somewhat to give it richer structure. There are three players in the game (a, b, c) endowed respectively with $(1, 2, 3)$ units of garbage. All players have the same cost of absorbing garbage on their property; if b units are absorbed the cost in numeraire dollars is b^2. The players are free to exchange garbage and money in any way they like and each agent's net cost $C(\cdot)$ will be the sum of net payments to others and the value of garbage ultimately absorbed. Thus, cost is measured in a common unit and this is a game of *transferable utility* in the parlance of game theory.

Given the convex cost of absorption, the efficient outcome here will be for agent a to absorb one unit of garbage from agent c (therefore generating equal absorption) in exchange for some compensation (the amount of which is irrelevant to efficiency) and we want to know whether free bargaining will lead to this outcome. We will examine this question under two different property rights regimes. Under the first which we label *exclusion rights*, no one can dump garbage unless rights are granted by the dumpee, whereas under the second (*possession rights*) the holder of garbage has the right to dispose of it as he likes, although he may be deterred by compensation. (In the air pollution analog, exclusion corresponds to the right to clean air, whereas possession corresponds to the right to pollute.)

6.2.1. Exclusion rights

Under the exclusion rule, any individual or subcoalition that chooses to go it alone must absorb their own garbage, but can prevent others from dumping on them. Using this rule, we can compute the cost to each coalition of going it alone. There are seven coalitions to consider: the three singletons, three pairs and the one grand coalition. We find:

$$C(a) = 1, \quad C(b) = 4, \quad C(c) = 9,$$
$$C(a, b) = 4.5, \quad C(a, c) = 8, \quad C(b, c) = 12.5,$$
$$C(a, b, c) = 12.$$

[25] See Shapley and Shubik (1969), the further discussion in Starrett (1973) and Aivazian and Callen (1981).

Note that in each case we have computed the total cost to the group so the cost is independent of money transfers among them and indicates the cheapest absorption cost they can jointly manage. So for coalition (a, b), they must absorb 3 units and the cheapest way is for each to absorb 3/2 at total cost $2(9/4) = 4.5$, and other costs are computed similarly.

A proposed allocation (*imputation* in the game theory literature) will assign a net dollar cost (u_i) to agent i. A necessary condition for this to be a core allocation is that for every coalition (Γ) the total costs imposed upon it be no greater than its value, that is:

$$\sum_{i \in \Gamma} u_i \leqslant C(\Gamma), \quad \text{for all } \Gamma. \tag{1}$$

When condition (1) fails we say that the allocation U is *blocked* by coalition Γ. In addition an allocation must be feasible for the group as a whole. This means that the grand allocation must absorb at least its value in cost. In conjunction with the corresponding constraint in (1), the grand coalition must absorb exactly its value, that is:

$$u_a + u_b + u_c = C(a, b, c) = 12. \tag{2}$$

Conditions (1) and (2) together characterize the core allocations. Any allocation satisfying these conditions cannot be blocked by any subcoalition and thus is stable against any potential defection. Note first that any allocation in the core must be Pareto efficient; otherwise it is blocked by the coalition of the whole. Thus as long as the core exists, bargaining under its rules will lead to an efficient outcome.

In the current situation we can verify existence by exhibiting a core allocation: $u = (0, 4, 8)$. Note that this corresponds to an efficient arrangement whereby agent c transfers one unit of garbage to agent a and pays him \$4 to accept it, while agent b simply absorbs his own garbage and is not involved in side payments. To verify that this is a core allocation we merely need check that no agent or pair of agents can do any better by defecting. For example, the pair (a, b) would incur costs \$4.5 by themselves and only incur \$4 under this proposal. The reader might note that the core is not unique here – there is some leeway in side payments that is consistent with the core side constraints. We would need to know more in order to specify a unique outcome. One possible conclusion would be that a market develops as in Section 2, and if there were enough players so that no one could influence the resulting price, that price would specify the equilibrium transfers.

6.2.2. Possession rights

When property rights are changed, we know that an income redistribution occurs and here that means that coalition values change. The question for us here is what effect if any this has on core allocations. Now, there is some ambiguity in what subcoalitions can expect if they defect. In particular, if agent a decides to go it alone (and dump his garbage elsewhere) what should he assume about the amount of garbage he will be forced to absorb? Here we will take the (fairly standard) position that he expects the worst – namely that all outside garbage will end up in his property. Note in particular, that this assumption makes core existence "most likely" since it makes defection "most costly". With this convention, coalition values are as follows:

$$C(a) = 25, \quad C(b) = 16, \quad C(c) = 9,$$
$$C(a,b) = 9, \quad C(a,c) = 4, \quad C(b,c) = 1,$$
$$C(a,b,c) = 12.$$

Now in searching for a core allocation we must at least satisfy the following pairwise coalition constraints:

$$u_a + u_b \leqslant 9, \quad u_a + u_c \leqslant 4, \quad u_b + u_c \leqslant 1.$$

Adding these constraints together and dividing by 2 yields

$$u_a + u_b + u_c \leqslant 7.$$

But there is no feasible allocation that satisfies this last inequality, so the core is empty.

The problem here is that with possession rights, it is tempting for a "large" subgroup (here of size 2) to gang up and dump everything on the lone outsider and there is no efficient way to absorb all the garbage without leaving some such subgroup an incentive to defect. It is not clear what we should expect to happen in this circumstance. Perhaps a powerful subcoalition will impose its will, but in principle the isolated party could always bribe them out of the corresponding inefficient dumping arrangement. More likely when negotiations break down, everybody will be forced to go it alone and again the outcome will be inefficient.

Thus, we see that in the absence of firm rules guaranteeing compliance and commitment, the arrangement of property rights can have a significant impact on the outcome, in particular determining whether or not bargaining will always generate an efficient outcome. Intuitively, this happens because the way in which rights are allocated helps determine what sanctions can be imposed on defectors, and these matter.

6.3. Perfect information requirement

Another necessary condition for validity of the Coase theorem is that there be perfect information – everyone must know what everybody else knows. In particular, each agent must know the preferences and characteristics of others. We illustrate with an example from insurance against personal injury. For simplicity, suppose the risk is binary – either you are hurt a fixed amount or not at all. Assume further that everyone agrees that the cost of the accident is a fixed number C. There are three kinds of agent. Two of these types are risk averse but differ in the probability of an accident (one being inherently more cautious than the other). The third type is risk neutral so will not demand insurance at fair odds, but will be willing to provide insurance to either of the other types at fair odds. In this world it is well known that the first best (Pareto efficient) outcome is for each risk averse type to receive full insurance at fair odds. However, if the insurer cannot tell the types apart, this outcome cannot be achieved since the bad (high risk) type will always want to portray himself as a good type. Consequently, the insurer would find herself writing all contracts at the good odds rate, would consequently lose money in expectation, and therefore would prefer not to do business.

The deterrent to efficient bargaining in the example emerges in a wide range of contexts. Whenever there is private information, then (ignoring the possibility of altruistic behavior) an agent has private incentive not to reveal information that will harm his bargaining position. But without this information it is not possible for the collective to know the efficient outcome, much less enforce it. Of course, in these situations, there will be incentives for the "good" types to signal their good information. However, the signaling itself must be costly in order to have credible information content, so that generally the resulting outcome still is not first best efficient.[26]

Thus, the validity of the Coase theorem in the presence of private information becomes one of optimal mechanism design.[27] Is it possible for an arbiter to design a system of messages and decisions/rewards based on messages so that the agents reveal a sufficient amount of their private information to specify an outcome that is Pareto efficient. Although there are some success stories here, there are serious limitations to what can be achieved. See Chapter 7 (by Baliga and Maskin) for discussion of mechanism design.

We conclude that bargaining alone is not likely to be a practical or efficient rule for managing the collective, especially when the required collective is large. From our perspective, this is unfortunate since many environmental collectives must be large in order to include all affected parties. For example, air pollution collectives must be at least national in scope. Worse yet, the ocean fisheries and greenhouse gasses collective must be global. Therefore in many environmental management situations we are left with a design problem of how to organize institutions and rules for exercising collective property rights in a way that best achieves goals of the relevant collectives.

7. Methods and rules for managing collective property rights

The mechanism design approach to management gives us a way of stating and analyzing the management problem in a precise mathematical language. However, there is a rich

[26] The classic reference in signalling is Spence (1975). See also discussion in Laffont (1987).

[27] For a survey of incentive issues as they relate to the allocation of public goods, see Laffont (1987). Various information issues are addressed in Schulze and d'Arge (1974), Dasgupta, Hammond and Maskin (1980) and Farrell (1987).

literature (both theoretical and empirical) that looks at the same range of issues in a much less formal way, with the general aim of assigning rights, identifying institutions and framing rules that will improve the allocation of collective resources even if full efficiency cannot be achieved.[28] Many structures have been studied involving ways of assigning and enforcing rights in such a way as to best elicit information and internalize externalities.

7.1. Self-organizing systems

Systems wherein collectives set up governance structures and enforcement procedures are sometimes referred to as "self-organizing" systems. Among the features of these systems that seem to generate the most desirable outcomes are (1) hierarchical structures whereby decisions with respect to a given collective good are made by an agency with the same collective constituency, (2) access rules and arrangements whereby users are well known to one another, (3) intertemporal structures whereby agents deal with each other on a repeated ongoing basis.[29] For each of these features there are sound reasons why they should be effective and some formal theoretical results.

Hierarchical structures have been studied formally primarily in the context of industrial organization.[30] There it has been shown that such structures often are an economical way of passing information within an organization and further that by designing the collectives of different sizes in the various layers of the hierarchy and decentralizing decision-making, it is possible to match the decision-making group to the relevant collective. For example, in the context of political collectives, the use of several layers of government (federal, state, country, city) enables decisions involving the national collective (such as national defense) to be made by the federal government, whereas those involving a local collective (for example, a city park) to be made by a more local (city) collective. Unfortunately, it is rarely possible to match the decision unit with appropriate collective exactly, in which case we must deal with spillover externalities whereby some of the benefits go to agents not in the decision collective. For example, in the case of the city park, benefits will generally accrue to visitors passing through from elsewhere. We discuss below the use of financial instruments to correct for these spillovers.

Arrangements whereby the decision-making agents are well known to each other and deal with each other on a regular ongoing basis foster cooperation in a number of ways. The desire to maintain a good reputation with peers provides incentives for agents to be truthful with each other and to follow collective rules. Further, when relationships are repeated over time, the collective can institute rules that serve to punish those who

[28] See, for example, surveys in Eggertsson (1990) and Bromley (1991).

[29] For further discussion of these issues, see, for example, Riker and Ordershook (1973) or Schotter (1981).

[30] See discussion and references in Demsetz (1988) and Williamson (1975).

do not cooperate as we saw in our discussion of repeated games, further bolstering the incentives to play by the cooperative rules.[31]

7.2. *Correction for externality*[32]

In situations where the decision collective is not exactly commensurate with the affected group, we expect externalities to occur – namely, some of the costs or benefits of action will fall on outsiders (as in our example where a city park is visited by outsiders). Whenever this happens, we expect incentives to be distorted in the same kinds of ways as we saw when private rights are assigned to collective resources. However, in these situations we may be able to use "market like" instruments to restore correct incentives. The standard method of correction for externality is to impose a tax per unit at the rate of external costs (or subsidy for external benefits). For example, since the burning of coal contributes to air pollution and global warming, a tax should be added to the price paid by users to producers of coal, the tax being equal to marginal social damages from these effects. In this way the price paid by users will reflect both the private costs of production and the social externality costs; then each user will equate the marginal benefit from use with the full marginal social cost, thereby generating a socially optimal use level.

This reasoning can be used to justify a variety of "green" taxes in situations where externalities damaging to the environment (from private decisions) can be identified. Of course, to reach the first best, we must be able to identify and measure the marginal external damage and monitor and enforce the volume of emissions so as to set appropriate tax rates and collect corresponding tax revenues. And agents have the same kind of incentives not to reveal their true preferences as we identified in connection with Coasian bargaining.

Even in situations where free rider externalities make it impossible to determine and/or enforce first best conservation principles, there are a variety of "second best" policies available that will be better than doing nothing. For example, a method widely used in the United States involves the setting of environmental standards – that is in the case of air pollution from the burning of coal, each polluter can be assigned a quota. As long as we are certain that the unregulated level of pollution is too high, a social improvement can be achieved by assigning quotas in such a way that the total emissions are reduced.

[31] We saw earlier how these ideas have been formalized in the theory of repeated games. In the empirical literature there is evidence that punishment strategies are used though not always in quite the way predicted by theory [see Ostrom (1990, 1999) and references therein].

[32] In the sequel of this section we will discuss remedies for externalities in the abstract. See Ashby and Anderson (1981), Kneese and Bower (1968) and Chapter 9 (by Stavins) for much more detail on practical matters of implementation. More detailed textbook treatments can be found in Hanley, Shogren and White (1997) and Kolstad (2000).

However, it has long been recognized that we can do even better than this by assigning initial rights to pollute (that correspond to the quotas above) and then allowing trade. An example of this method is the use of emission permits to regulate the atmospheric concentration of SO_2. Unless we can correctly measure people's disutility from smog we may not be able to determine the optimal concentration. However, whatever concentration is chosen, we can use tradeable permits as a vehicle for achieving that level in a least cost manner. Further, by varying the ways in which permits are assigned, we may be able to alter the distribution of income in desirable ways.

Let us see how this might work for the case of SO_2. First we would need to identify the region to be regulated and all the sources of emissions in this region. Further we must have a monitoring system in place that enables the regulator to verify levels of emissions. Next, we assign property rights by giving an initial allocation of permits (rights to emit a pound (or ton) of SO_2 into the atmosphere) to each emitter. Then they can be allowed to buy additional permits or sell some of their allocation on a permit market. Just as in the case of the garbage example discussed at the outset, if different emitters have different opportunity costs of emissions, there will be trades on this market (with high cost emitters purchasing from those with lower costs) and in equilibrium total emissions will be achieved at least opportunity cost. And if we observe voluntary trades taking place, we can be sure that the emissions market is Pareto superior to the simple setting of standards. Further, note that the information requirements are the same. In both cases, we must be able to monitor the levels of emissions, but nothing else.

Assuming that the emitters are all firms, the distribution of income will be affected by the rights assignment only indirectly through the ownership shares in these firms. Alternatively, we could affect the distribution directly by assigning rights to consumers (or consumer groups) and requiring firms to purchase rights to pollute from them. This would be tantamount to giving those consumers rights to clean air and requiring polluters to compensate them for degradation. Returning to our earlier discussions of efficiency versus equity, we see that there is some scope in the assignment of these kinds of property rights to affect the distribution of income in a way that does not distort incentives. Indeed, it has been suggested in the "north/south" debate that rights to global pollution should be assigned in such a way as to transfer wealth from the "have" (north) nations to the "have not" (south). Unfortunately the scope for such transfers (even if the political will is there) are probably too small to eliminate the efficiency–equity conflict.[33]

It is worth pointing out that aside from distributional considerations the outcome achieved by a permit market can also be achieved through the use of an externality tax.[34] Any equilibrium permit price could have been imposed as a tax rate and thereby achieve roughly the same total emissions level with the same degree of efficiency. However, now

[33] For discussion of the special problems that are present when appropriate collectives cross national boundaries, see Dasgupta and Mäler (1992).

[34] For a theoretical analysis of different pollution control instruments, including emissions trading, emissions taxes, and regulatory standards, see Chapter 6 (by Helfand, Berck and Maull).

the informational requirements for the two schemes are different. In a permit scheme, the total quantity is specified and the marginal valuation is revealed by the equilibrium permit price, whereas in a tax scheme, the price is specified and total emissions revealed through choice.

This distinction takes on extra significance in a world of uncertainty. When there is uncertainty in economic production relationships, if quantity is specified, this uncertainty will show up in random variation in the associated price, whereas if price is specified there will be random variation in the corresponding quantity. Thus, in this situation, there may be a preference between these two methods depending on which uncertainty is more costly.[35]

8. Conclusions

We have discussed in this chapter the various ways in which property rights can be assigned to environmental resources and indicated which type of rights are appropriate depending on the characteristics of the associated resource. While indicating that there is no magic bullet that will solve all collective resource problems, we have identified ways of improving collective allocations and cited evidence that motivated groups sometimes do a better job of management when collective rights are properly identified than might have been predicted by theory. Thus, while recognizing that environmental problems are acute, we believe that careful management of collective property rights has considerable potential for generating improvements.

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[35] See Weitzman (1974) and Dasgupta, Hammond and Maskin (1980).

[36] Rather than attempt to cite all relevant secondary sources, we have chosen to list a few seminal pieces and the major tertiary (textbook, handbook and monograph) sources.

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