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The Environment as a Commodity

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THE ENVIRONMENT AS A COMMODITY

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I The Production of Commodities by Means of Resources

All economic activity is based ultimately on resources found in nature. Whether it is consumption or production, or whether it is exchange, the commodities which are involved are made of constituents provided by nature. Thus, the ingredients of any manufactured good are other produced goods, labour time and skills, and natural resources. Now, each of these constituent produced goods is in turn made up of the ingredients that went into its manufacture, namely, labour time and skills, natural resources and further produced goods. It follows that any manufactured commodity is ultimately a combination of labour and natural resources.

Now, labour too is a produced good. Even raw labour power is an output, manufactured by those natural resources which sustain life, resources such as the multitude of nutrients we consume, the air we breathe and the water we drink. All commodities are therefore traceable to natural resources.

The point in exposing the morphology of produced goods and services is not to construct a resource theory of value. There are any number of natural resources, and this alone precludes such an attempted theory from being coherent. My purpose, rather, is to use it to express surprise at the fact that despite the centrality of natural resources in economic activity, they find little room in economics discourses. Interest in resource economics, more particularly

environmental economics, has only been intermittent, and if we are currently witnessing a resurgence, we have also just lived through a decade-long neglect, during which much valuable work could have been done.[1] We are way behind where we should have been, and could have been, to confront the many environmental problems we have again become conscious of.

In fact, there is another problem with periodic intellectual slumber. It is that with each reawakening, much of what had been developed earlier is not known or acknowledged: economists are notoriously ignorant of intellectual capital. (In many instances, however, the extent of ignorance is so astonishing that one can only assume it is feigned.) Much energy is then spent rediscovering ideas. Thus, there is no credible reason today why economists should have to write on the analytical foundations of environmental charges, or of the informational parsimony afforded by transferable pollution permits. Nor is there any reason why politicians and journalists and international agencies have now to be told that estimates of net national product ought to take account of the degradation of environmental stocks; nor indeed, why we need now to try and fathom what "sustainable development" might plausibly mean; or what ethical drive the concept of social discount rates may possess. These issues were the subject of a pretty successful research programme among technical economists a decade and a half ago.[2] As subjects for analytical investigation, these topics are now very cold. As research problems they are dead.

More generally, there is even today a widespread misconception that "economic" calculations and environmental concerns are in conflict. The view is so pervasive that thoughtful commentators on the environment often find it necessary first to state it and then to correct it by talking of the resurgence of "green economics" (see, for example, The Economist, 2 September 1989). In fact, this greening began a long while ago, at least as far back as Pigou (1920) in his classic development of the concept of externalities, and his exposure of the difference between private and social costs (and benefits) in the phenomenon of externalities. Pigou, of course, did not complete the analysis. He couldn't, because there were analytical difficulties he was incapable of handling, most especially those connected with time, uncertainty and the pervasiveness of asymmetric information, and those involving a small number of economic agents.[3] During the decade of the 1960s, and even more the decade of the 1970s, what we today call environmental economics, and more generally resource economics, was developed and codified. (See, e.g. Coase (1960), Kneese (1964), Brown and McGuire (1967), Krutilla (1967), Dales (1968), Arrow (1971), Starrett (1972), Meade (1973), Arrow and Fisher (1974), Mäler (1974), Baumol and Oates (1975), Kneese and Schultze (1975), Krutilla and Fisher (1975), Review of Economic Studies (Symposium, 1975), Clark (1976), Mäler and Wyzga (1976), Dasgupta and Heal (1979), Dasgupta (1982) and Lind ed. (1982). Excellent elementary texts on the subject are Hartwick and Olewiler (1986) and Tietenberg (1988). Ulph (1989) is a useful readers' guide to existing textbooks and treatises on the subject.) Its

incorporation into development economics, especially development planning, has been rather slower. (For an early attempt, see Dasgupta, 1982.) But the analytical bits and pieces are all available for use.

In this essay, I won't produce a litany of environmental losses. This has been done to great and fruitful effect by others more knowledgeable on these matters. (See, for example, the documents published regularly by the Worldwatch Institute in Washington, D.C., and the several State of the Environment Reports; e.g. Agarwal et al., 1982, 1986; IIED/WRI, 1987). I shall approach matters instead from the analytical corner and borrow from the literature which I have cited to provide an outline of the main features of the economics of the environment.

By an environmental problem I don't of course mean only the classical one of the factory chimney polluting the atmosphere. I mean a great deal more, and I shall try and present a unified viewpoint which will be wide enough to catch within its net a seemingly disparate class of resource problems. The advantage of a unified formulation is that it enables us to economise in our thinking. Given an embracing framework, we can borrow from our understanding of one class of issues when we consider some other class of issues. And it puts the onus on us to prove when we claim, as we rightly do in many cases, that a given environmental problem has its own special features, reflected not only by the specific nature of the resource under study, but also by its location, the time

in question, and the socio-economic context in which it occurs.

As it happens, even here there are a number of routes along which one can enter a discussion. I shall, to begin with, adopt one which is hallowed by tradition, and is in other respects as good as any other route. Later in this article (Section VI), I shall adopt a different route. We will see that the two will have the same implications for public policy. Our starting gate will therefore not matter. The two avenues will lead us to the same destination.

II Missing Markets and the Breakdown of Social Norms

I want to begin by thinking of market failure and I begin with the observation that in many cases where markets malfunction, their malfunctioning can be ascribed to the fact that for certain commodities markets simply don't exist. Sometimes they happen not to exist for accidental or historical reasons, sometimes there are logical reasons why they can't exist, sometimes the nature of the physical and political situation keeps them from existing, or makes them function desperately wrongly when they do exist. What are usually called environmental resources are, as it happens, particularly vulnerable to this problem.

By markets I don't necessarily mean price-guided institutions, I mean something a good deal more general. By markets I mean institutions which make available to affected

parties the opportunity to negotiate courses of actions. And by malfunctioning markets I mean circumstances where such opportunities aren't present, or where they are at best present only partially, or where they are somewhat one-sided. (This last, the often one-sidedness of opportunities, means that I am thinking of distributional issues as well, not merely those bearing on efficiency.) The existence of competitive market prices presupposes only one set of special institutional arrangements within which such negotiations can take place (as it happens they render unnecessary any negotiation!). Bilateral bargaining is another; and there are a whole host of intermediate institutions, those providing the scope for multilateral bargaining, the agreements arising from which are on occasion codified over the years through the emergence of social norms, and the associated social sanctions imposed upon those in violation of such norms; and upon those who fail to impose sanctions upon those in violation of such norms; and upon those who fail to impose sanctions upon those who fail to impose sanctions upon those in violation of such norms, and so on indefinitely.

This is important to recognise, that social norms can be seen as implicit social contracts. Put another way, social norms are strategies of behaviour. But they are strategies that are sustained by self-enforcement, and not by the law courts. Provided people are not unduly myopic (see Appendix), the contract can be enforced if each person were able credibly to threaten a withdrawal of his co-operation from any person who violates the contract. Since so much of resource

management in traditional societies has been sustained by norms of behaviour, I shall try and make all this a bit more precise. It will also suggest why norms can break down during periods of change. And if they are not replaced by new, effective norms, the society begins to suffer from "market failure."[4]

At any date, call a person a conformist if he co-operates with a person if and only if that person had shown himself at the previous date to have been a conformist.[5] At the starting date, we define a conformist to be one who co-operates; that is, one who keeps his side of the bargain. From the definition of a conformist, this society can then recursively determine at any future date whether a given person is a conformist. It is then possible to show that if people aren't unduly myopic, it is in the self-interest of each person to be a conformist were all others to conform. (See the innovative paper of Abreu, 1987. See also Costa, 1987.) But this means that universal conformism is self-enforcing.

Notice that the social norm in this example is conformism. A non-conformist is a deviant. And a conformist punishes him by withdrawing his co-operation. Thus, in particular, a conformist punishes a person who has failed to punish someone who has violated the social norm. This is because in failing to punish the violator, the person in question himself is a violator of the social norm! In the Appendix, I will present the simplest version of the formal argument. It will make clear the role individual discount

rates play in sustaining social norms, and thus tacit co-operation. But even this informal account demonstrates that my starting gate, the phenomenon of market failure, has allowed me immediate access to the province of anthropologists who have so often illuminated our understanding of customs regarding the use of environmental resources in communities that are at first sight not easy to comprehend. As it happens, such social customs are often instrumental in supporting objectives that are not dissimilar to those of a "modern" bent, and they are often under erosion - this is the market failure - through shifting demographic features, newly emerging economic opportunities and changing social mores and lifestyles. Recent work on the theory of bargaining, particularly in the context of repeated games, has shown how fragile such social customs can be, how dependent they are on the ability of affected parties to monitor the actions of others - that is, compliance of implicit contracts - and on the ability of each party to assess the value that others attach to the resource in question. And so on. I shall come back to these issues in the following section.

III Reciprocal Externalities

Much of this has been studied under the general rubric of what is today called the Problem of the Commons, a problem which is associated with resources to which no property rights have been awarded. Such resources are therefore free to all who wish to avail themselves of them. Being free and finitely available they are used excessively. (One needs to add some

qualifications to make this inference, but I will ignore theoretical niceties here.) We may conclude that the social value, or accounting price, of a "common property" resource is positive, on occasion large and positive, even while it is free to individual users.

Such resources abound. The earth's atmosphere, which is in a continual state of diffusion, is a paradigm. It is a global commons, and such problems as are thought to arise from that part of carbon dioxide emission which is not recycled by vegetation and plankton are global problems and have to be attacked at an international level of discourse. Moreover, all nations will have to be involved in the negotiation. It won't be enough if only a few nations agree on a joint co-ordinated policy; those not party to the agreement will follow policies that will vitiate the point of the agreement. So too with other global commons, such as international fisheries, deep-sea nodules and the international waters as a repository of our garbage. The United Nations Law of the Sea Conferences have been an instance of this, not an inspiring instance, but it was better to have had them than not.

The global commons associated with carbon dioxide emission poses particularly interesting questions because it is twin-edged. Recall that the common property here is the earth's atmosphere, measured by a quality index, what one might call a generalised ambient air-quality index. The burning of fossil fuels adds to the emission of carbon dioxide. If the greenhouse effect is indeed significant and if

this in fact does lead to overall damages in crop production, fisheries, habitation and so forth, we would say that cet. par. the emission of carbon dioxide lowers this quality index. As we noted earlier, from the fact that we are all free to emit carbon dioxide we may conclude that we emit too much of it. This is a problem of global commons with a vengeance. Unhappily, it is only one side of the matter. The other side is the fact that carbon dioxide is recycled by plants and vegetation, and if their stock is allowed to fall, the retention of carbon dioxide by the atmosphere will be increased. Brazil is one major repository of such vegetation. Notice that the private cost to Brazil in pursuing a depletion policy - insofar as the carbon dioxide issue is concerned - will be far less than the global cost. Brazil won't take account of the damages incurred by the rest of the world. So then, one will expect Brazil to deplete at a faster pace than is globally warranted, thus exacerbating the carbon dioxide problem. As it happens, Brazil is engaged in a murderous depletion policy. The gap between theory and application in environmental economics is pleasantly a narrow one.

So then what is one to do? I can't think it will do to look solemn and utter pious sentiments concerning our moral duty. Morality is a scarce resource, and one needs to economise its use when considering implementable public policy. Truly multilateral bargaining about reductions in carbon dioxide emission is one way. However, multilateral bargaining, leading to mutual reduction in pollution emission is a plausible way only when the problem is somewhat common,

and is perceived to be common, with the stakes being roughly the same for all parties. This is so when the damages which are inflicted are reciprocal; that is, when each of the parties damages all the other parties through its actions to pretty much the same extent. It is a less feasible way when the damage is somewhat unilateral, as with Brazilian deforestation. The idea of international compensation to the depleter for reducing the rate of depletion should no longer be regarded as far-fetched. Partial debt-relief for a lower rate of plunder of the Amazonian forest is something that will probably be on the agenda in the near future. This is Pigouvian subsidy. It is hard to imagine that there are many other options open to us.

I have begun with global commons because they are as good as any on which to fix ideas, and in any case they are the ones that receive the greatest attention in both the national and international press. But as we go about our daily lives, it is local commons which we encounter most often. Their effect is more immediate and is often shattering, most especially for those whose livelihood is based directly on them. Overgrazing, overfishing, the depletion of trees and shrubs from common land for use as fuel are familiar problems. They are traceable to the common property nature of such resources as grazing land, fisheries and forest cover. So too with the drawing of water from aquifers which by the nature of things must usually be common property even when the land covering the aquifer is privately owned.[6]

One reason why the problem of the commons has been studied so intensively by economists is that the policy issues they give rise to possess the agreeable feature of our not having to choose between equity and efficiency. If the users of a common property resource are pretty much symmetrically placed, a joint policy of restricting their use will be beneficial to all, and to pretty much the same extent. It may even save the resource from ruin and this will benefit users who are not currently a party to the social contract. Nothing could be nicer.

IV Commons, Customs and Norms

It may seem that geographically localised commons have a better chance of being protected from excessive use than global commons. It isn't so much the smaller number of users that make local commons easier to manage, it is rather that the users' activities are easier to monitor. If private action cannot be monitored publicly, sanctions can't be imposed on violators, and a social contract, even if it were to be reached, would amount to nothing. An unenforceable contract is no contract. Then of course, there is the question whether an agreement would in practice be reached. Agreement is presumably easier to reach if the parties have long known one another, expect to continue to know one another, and hope to avail themselves of the resource for a long while. It isn't merely a question of social niceties, although this can be important. It is also that the parties are then likely to know

how the resource is valued by each. (This is important, although it is often overlooked in discussions on these matters. You cannot effectively bargain with someone if you have no clue what his values are. Indeed, you may think that he thinks there is nothing to bargain over; that is, there is no mutually beneficial set of actions to agree upon.) And finally, yet another reason why these conditions are a pre-requisite is that it is only under such circumstances that each party will have a long term interest in the resource. It will then discount its future value at a low rate. This, as I shall argue in a rather different context, is in practice of great significance.

Social contracts, whether or not they are explicit, have to be simple to be effective. More specifically, contractual obligations need to be pretty much invariant across states of nature, or eventualities. This is partly because the mind has limited capacity for processing information, for evaluating information and for acting upon information. And so it won't do for a contract to have too many qualifications, to allow for too many exceptions to the rule. But it is partly also because a great many states of nature are only privately observable, and not publicly confirmable, and one should recall that obligations which are conditional only on privately observable states of nature are not enforceable, unless they are compatible with private incentives.[7] For these reasons, social contracts need to be simple if they are to promote individual or group well-being. As we noted earlier, social norms can be regarded as implicit contractual

obligations.[8] In stationary socio-economic environments they are enshrined in customs and rituals, with the result that the contractual behaviour is adopted effortlessly. If you are steeped in norms that are socially codified, you don't calculate every five minutes how you should behave. You simply follow the norm. This saves on computation costs all round, not only for you as an actor, but also for you as "policeman" and "judge." This will be fine so long as the background environment remains pretty much the same. But it won't be fine if the environment changes suddenly. You might even be destroyed. It is this heightened vulnerability, often more real than perceived, which is the cause of some of the greatest social tragedies in contemporary society. This additional vulnerability is brought in their wake by shifting populations, ageing populations, predatory governments and thieving aristocracies (see Sections V and VI), and technological progress; but part of the underlying causes are an absence of adequate property rights and the psychological and learning costs involved in altering one's behavioural norms. As noted earlier, a stationary society need not tamper with the commonality of a common property; it can arrive at an efficient use through an implicit contract. The tragedy I am alluding to is the breakdown of the contract unreplaced by a new and, for the historical users, beneficial contract. The locus of the problem doesn't usually lie in the place identified by Hardin (1968) in his famous essay. It lies where I have identified it.

V Unidirectional Externalities

A defining characteristic of the problem of the commons is its reciprocal nature. If I bring an additional cow into the common pasture I harm you and all other cattle people: there will be just that much less grass for your cattle and for those of others. If you bring an additional cow into the pasture you harm me and all other cattle people.

The commons may, of course, involve many economic actors. In this situation, the damage each actor inflicts on one is often negligible. But the sum of the damages inflicted by the many on one can be substantial.[9] Now, all this makes for a certain simplicity of analysis and, as we have noted, for an ease in locating mutually beneficial policies. Matters are greatly more problematic, in need usually of public action, for damages which are unilaterally inflicted. A most significant instance of this is deforestation in the uplands inflicting damage on the lowlands. As always, it pays to concentrate first on the assignment of property rights before seeking remedies. The common law, if one may be permitted to use this expression in a universal context, usually recognises pollutors' rights, not those of the pollutees. Translated into our present example this means that the timber merchant who has obtained a concession in the upland forests is under no obligation to compensate farmers in the lowlands. If the farmers want to reduce the risk of heightened floods, it is they who have to compensate the timber merchant for reducing the rate of deforestation. Stated this way the matter does

look morally bizarre, but it is how things are. Had property rights been the other way round, one of pollutees' rights, the boots would have been on the other set of feet, and it would be the timber merchant who would have had to pay compensation to farmers for the right to inflict the damages that go with deforestation. However, when the cause of the damage is located hundreds of miles away and when the victims are thousands of impoverished farmers, the issue of a bargained outcome doesn't really arise. It is difficult to see such farmers grouping effectively as a negotiating party. Judged even from the viewpoint of efficiency, the system of pollutors' rights in such an example is disastrous. We would expect excessive deforestation. The timber merchant, it will be recalled, doesn't have to compensate the lowland farmers. Put another way, the merchant's private cost of logging falls short of its social cost. The problem is exacerbated if the timber concession is a short-lived one and if the concession is not allied to any serious form of public regulation. In such situations the merchant would discount the future value of the forest at a high rate, and thereby log at a fast rate, faster than what the long view would warrant. The combined effect of high rates of discount and the infliction of damages to farmers can be shattering, and we now see evidence of this in many parts of the globe.

In each of the examples I have so far alluded to, whether it involves reciprocal damages (as in the problem of the commons) or unidirectional ones (as with upland deforestation) there is a wedge between the private and social costs

associated with the use of some natural resource: in extreme cases private costs are nil. But the fact that social costs are higher, sometimes a great deal higher, means that other things being the same, resource based goods are underpriced in the market. Quite obviously, the less roundabout, or less distant, the production of the final good from its resource-base the greater is this underpricing, in percentage terms. Put another way, the lower the value added to the resource, the larger the extent of this underpricing of the final product. We can conclude therefore that countries which export primary products do so by subsidising them, possibly at a massive scale. Moreover, the subsidy is paid not by the general public via taxation, but by some of the most disadvantaged members of society: the share-cropper, the small landholder or tenant farmer, and so on. The subsidy is hidden from public scrutiny; that is why nobody talks of it. But it is there. It is real. Such subsidies are both inefficient and inequitable. We should be in a position to estimate them. As of now we have not such estimates. They haven't even been acknowledged in public discussions.

VI Government Failure

All expositions on the economics of environmental resources with which I am familiar begin with market failure. There are pedagogical advantages in our doing so. This is why I began with it here. But once you start from there, you know what the next step is. It is to develop a conceptual basis for

government intervention - in the design of environmental taxes, regulations, licenses and so forth.[10]

But in fact we could as well have begun from the opposite end: the failure of centralised modes of control in the allocation of resources. The record of East European governments on environmental matters is as good a starting point as any. Now, the reasons why we wouldn't expect systems of centralised control and command to work well are familiar. There is, first of all, the enormous potential for corruption to become ingrained in a system where bureaucrats and the military have extensive powers to control resources. There is also a technical reason. It has to do with the massive quantities of information a centralised agency would be required to possess and process if it were to apply controls effectively. No single agency can ever obtain such amounts, let alone use it in a reliable manner. It is, of course, the single most telling characteristic of decentralised resource allocation mechanisms that information is decentralised in them. In the field of environmental resources, where matters pertain to soil erosion, deforestation, air and water pollution, fisheries extraction and so forth, the necessity of relying on mechanisms which make essential use of dispersed information is immediate.

It follows therefore that ideal resource allocation mechanisms are mixed "market" systems, where "markets" are allied to judicious forms of government intervention in the allocation of a wide range of resources.[11] Current experiments

in the United States with transferable permits in the field of pollution is an instance of this. (See Dales, 1968, for the original proposal. See also Tietenberg, 1980, for a review.) A fixed number of marketable permits has two virtues at once. It first of all puts a ceiling on total emission in any given period. If this ceiling is chosen judiciously, there is little chance that serious damage will occur. Secondly, their marketability means that polluting firms' private information concerning their technologies is allowed to play an effective role in the allocation of these permits among them. The conceptual simplicity of tradeable permits has much to commend it. But at an analytical level, there are superior allocation mechanisms. They involve firm-specific, non-linear pollution taxes. (See Dasgupta, Hammond and Maskin, 1980. See also Dasgupta, 1982, Chapter 4.)

Let us recall that an environmental problem exists whenever there is a gap between the accounting price of a natural resource and its actual, or market price.[12] In earlier sections we have seen that such a gap can arise because of missing markets. But, of course, it can arise also as a direct consequence of faulty government policy. When the State subsidises the use of pesticides and fertilizers with an eye solely to agricultural production, it creates a wedge between their accounting and market prices. This is because it hasn't simultaneously kept an eye on the environmental damage that in future will be triggered by the chemicals. More generally, when public policy is determined under the supposition that natural resources are unlimited, a gap appears between

accounting and actual prices. Nowhere has this been occasioned more dramatically than in the process of conversion of agricultural and forest land into ranches and unused, denuded land in Latin America. What has attracted most attention in recent years is the deforestation of the Amazon Basin accompanying this territorial expansion. In an early and neglected pair of articles, Feder (1977, 1979) described how massive private investment in the expansion of beef cattle production in fragile ecological conditions has been supported by domestic governments in the form of tax concessions and provision of infrastructure, and by loans from international agencies.[13] As a case study in policy mismanagement - more accurately, as an example of predatory behaviour on the part of the State - this one is difficult to improve upon. Government policy, prompted by the landed and industrial aristocracy, and the military, and aided by international agencies, was instrumental in degrading vast tracts of valuable environmental resources. And it simultaneously disenfranchised large numbers of small farmers and agriculture labourers from the economy, and made at best destitutes of traditional forest dwellers. There is absolutely nothing to commend it.[14]

As with market failure, government failure of the kind we have just studied results in an excessive use of environmental resources. We can conclude then that policy reversals designed to remove such self-inflicted distortion can be expected to yield at least two kinds of benefits: an increase in aggregate income and a discouragement of excessive environmental

destruction. And to top it, such policy reversals could well improve the well-being of the poorest in society. Feder's analysis of Latin American agribusiness suggests this last strongly.

VII The Environment as Renewable Natural Resources

Thus far we have been thinking of environmental resources as those naturally occurring commodities and services whose markets malfunction for a particular set of reasons: those arising from imperfectly monitorable rights of use, and in extreme cases from an absence of specified rights. As we have noted, this allows us to draw fairly strong conclusions about appropriate public policy.

But it is only a partial view. It is a view from the institutional side of things. There is another, complementary perspective from which one may look at environmental resources. It is to study their physical characteristics. As it happens, there is a simple and useful way of describing them, one which I elaborated upon in Dasgupta (1982). I will sketch this now.

Environmental problems are almost always associated with resources that are naturally regenerative - we could call them renewable natural resources - but which are in danger of exhaustion from excessive use.[15] Notice first that this is very much consonant with common parlance. Resources such as minerals and fossil fuels don't fall into this category; they

are non-renewable, except in geological time. One should also note that we usually don't regard the depletion of a non-renewable resource as an environmental issue, except insofar as the act of extraction and use in production have "environmental effects." Thus to take two examples, the burning of fossil fuels increases the global mean temperature, and the smelting of ores is a common source of atmospheric pollution. The environmental issue here, as it is usually understood, pertains not to the fact that the world's supply of fossil fuels and minerals is being reduced, but rather to the fact that such activities have a deleterious effect on the earth's atmosphere, which is a renewable natural resource. In these examples, the atmosphere is used as a sort of sink, a repository of certain forms of waste products. Stated only a bit differently, we are concerned here with natural resources which are capable of regenerating themselves so long as the "environment" in which they are nurtured remains favourable.

The earth's atmosphere, as we noted earlier, is a paradigm of such resources. Under normal courses of events the atmosphere regenerates itself in terms of its composition. But the speed of regeneration depends upon the rate at which pollutants are deposited into it and it depends also on the nature of the pollutant. (Smoke discharge is clearly different from the release of radioactive material.[16]) Now, whenever we talk of a resource, we should think of its stock and of ways of measuring it. In the case at hand we ought to think of an atmospheric quality index. We ought also to think about its rate of regeneration. This last will depend upon the nature

and extent of the pollutions discharged. It will however also depend upon the current index of quality; that is, the current level of stock. These are immensely complex, ill-understood matters. There is a great deal of synergism associated with the interaction of different types of pollutants in the atmospheric sink, but the analytical point I am making remains a valid one.

Animal, bird, plant and fish populations are also typical examples of renewable natural resources. And there are today a number of studies connected with the reproductive behaviour of different species under a wide variety of "environmental" conditions, including the presence of parasitic and symbiotic neighbours. (For the use of such ideas in economic models, see Barrett, 1989.) So is land such a commodity, for the quality of arable and grazing land can be maintained by careful use. Overuse however impoverishes the soil and eventually produces a wasteland. (The symbiotic relation between soil quality and vegetation cover is of course at the heart of the current anxiety over sub-Saharan erosion.)

Underground basins of water often have a similar characteristic, the matter being even more problematic because we are concerned both about its quality and quantity. Under normal circumstances an aquifer undergoes a self-cleansing process as pollutants are deposited into it. But the effectiveness of the process depends, as always, on the nature of the pollutants and the rate at which they are discharged. Furthermore, a great many aquifers are recharged over the

annual cycle. If however the rate of water extraction exceeds the recharge rate, the water table drops, thereby raising extraction costs. In fact aquifers display another characteristic. On occasion the issue isn't one of depositing pollutants into them. If, as a consequence of excessive extraction, the water table is allowed to fall to too low a level, then in the case of coastal aquifers there can be salt-water intrusion, resulting in the destruction of the basin.

I conclude from these examples that one unifying characteristic of environmental resources is their regenerative capability, a capacity which can be destroyed if they are exploited unwittingly. In this sense, issues concerning what is usually labelled "pollution" can be studied in the same general sort of way as those concerning animal, bird, plant and fish populations, aquifers, forests and soil quality.[17] And this brings us naturally back to a point already made, that markets for such resources can easily function badly. If we now add to this a further point we have noted, that their malfunctioning is biased, that for reasons we have identified there is a strong tendency towards excessive use, rather than insufficient use, then we begin to obtain a consistent picture of what we are up against and what policy debates should be about.

It is worth reiterating the importance of viewing these commodities as renewable natural resources. They force us to look at the intertemporal structure of economic policies with all its attendant difficulties. Stated this way one may be led

to think that we are up against yet another problem in what economists have labelled "capital theory," of which we have a good understanding. It is certainly such a problem, but it is allied to a number of additional complexities, of which one central class was discussed at some length earlier, concerning imperfectly operating rights. But there is another class of problems associated with environmental resources, and I want to probe it a bit in what follows.

VIII National Net Product

To begin with, the kinds of resources we are thinking of are, on occasion, of direct use in consumption (as with fisheries), in production (as with plankton, which serve as food for fish species), or in both (as with drinking and irrigation water). Their stock is measured in different ways, depending on the resource: in mass units (e.g. biomass for fisheries), in quality indices (e.g. air and water quality), in volume units (e.g. acre-feet for aquifers), and so on. When we express concern about environmental matters we in effect point to a decline in their stock. Environmental resources are therefore a part of our capital assets. And yet, we have little quantitative feel for the extent of these stocks and their rates of change. There are countries which suffer from an almost total paucity of information on the extent of their forest cover, rates of soil erosion, water supply and so forth. This gets reflected in the biased manner in which indices of economic performance are computed. In what follows,

we will discuss the most common indicator of aggregate well-being: real net domestic product.[18]

Real net domestic product estimates are in bad odour today. It is often thought that such estimates are even in principle incapable of reflecting aggregate well-being. This is not correct. For it is possible to show that, subject to certain technical restrictions, for any conception of aggregate well-being there exists a set of (agent-relative) accounting prices which, if used in the estimation of net domestic product, will ensure that the measure reflects aggregate well-being. (See Dasgupta and Weale, 1989.)[19]

Now, this is a statement of principle. In practice, estimates of net domestic product are biased, in that the prices which are used for valuing certain categories of goods are systematically different from their accounting prices. This is especially so for natural resources, and for reasons we have already identified: their accounting prices are positive, but their values are set at zero in estimates of net domestic product.

Real net domestic product is the sum of the social (or accounting) value of an economy's consumptions and the social value of the changes in its stocks of real capital assets.[20] Provided accounting prices have been estimated accurately, an optimising economy will choose the flow of its consumptions and net investments so as to maximise real net domestic product at each date.[21] It was shown by Samuelson (1965) and Weitzman (1976) that real net domestic product at any date

along an optimal economic path reflects its long-run consumption possibilities. But they proved it in the context of economies that are capable of sustaining a steady economic state; that is, those that can maintain a balanced composition of all assets. Now, this precludes exhaustible resources. Dasgupta and Heal (1979) and Dasgupta (1982) showed how exhaustible and renewable natural resources should be incorporated into an ideal measure of real net domestic product. Thus, for example, when net domestic product of a country is estimated, the depreciation of fixed capital is deducted. An ideal index would deduct depreciation of the country's natural resource stocks as well - valued, of course, at accounting prices.[22] To the best of my knowledge, no country as yet deducts this latter magnitude, even while it simultaneously expresses concern about its declining resource base. This is schizophrenia with a vengeance. The reason for this dual attitude isn't hard to find. It is connected with the characteristics of market failure we discussed earlier. But it is more pernicious in the present context because governments ought to know better than to fail to impute any value to an entire set of capital assets. Real net domestic product is therefore lower than it is currently estimated. This is almost certainly so for all countries. It is also almost certainly the case therefore that the rates of growth of net domestic product are lower than what they are alleged to be.

The question arises whether these biases are in practice quantitatively significant. Rough and ready calculations

suggest that environmental losses amount only to some 1-3% of national income, not more.[23] If true, such corrections as those I have been advocating here would seem hardly worth the bother.

In fact they are very much worth the bother. Recall that when correctly estimated, net national product is a measure of long run consumption possibilities facing an economy. Therefore, when we ignore environmental depreciation we may well be way off the mark in our estimate of the economy's rate of growth of net national product. Our assessment of the economy's performance could be quite wrong.

To see this, let Y(t) be net national product (as conventionally measured) in year t, and let D(t) be environmental depreciation at t.[24] Consider two adjacent years, say 1 and 2. Suppose D(1)/Y(1) = 0.01. Being only 1% of national product, environmental depreciation is negligible. Now suppose [Y(2) - Y(1)]/Y(1) = 0.02. This is a fairly healthy growth rate, and we would be tempted to commend the economy. However, this increase in national output may have come about at the expense of environmental stocks: soil erosion, groundwater depletion, deforestation, and so forth. We would not know this if these losses were not to appear in national income accounts. Thus, suppose that D(2)/Y(1) = 0.03. As a ratio of national product, environmental losses are still negligible. But the real growth in net national product is not 2%, but rather

$$\{[Y(2) - D(2)] - [Y(1) - D(1)]\} / [Y(1) - D(1)]$$

and this is zero. The economy hasn't actually grown at all. Our assessment of the economy should be quite different now.

Difficulties associated with the estimation of real net domestic product are compounded by the fact that unlike computers and tractors, environmental resources usually affect welfare directly as stocks, not merely as service flows. (An exception is noise pollution.) Fisheries and aquifers are useful not only for the harvest they provide (this is the flow); as a stock they are directly useful, because harvesting and extraction costs are low if stocks are large. Tropical forests are beneficial not only for the timber they may supply (this is the flow of service); as a stock they prevent soil erosion and, in the case of large tropical forests, help maintain a varied genetic pool and contribute substantially to the recycling of carbon dioxide. Likewise, air and water quality have direct well-being effects (it is, let us remember, the concentration of pollutants which is relevant here). And finally, the direct effect of the stock of ozone in the ozone layer on the flow of well-being is obvious.

The direct well-being effects of environmental resource stocks are in some cases relatively easy to estimate, as with fisheries and groundwater, in others pretty near impossibly difficult. But the point remains that ignoring what one might refer to as environmental overhead durable consumption leads

to a further bias in estimates of real net domestic product, in the direction of overestimation.

To make this precise, let us assume that aggregate well-being in an economy at any given date, t, depends not only on the flow of consumption, C(t), but also directly on the stock of its assets, S(t).[25] Let W(C(t), S(t)) denote the flow of aggregate well-being at t. Using the all-purpose commodity as our numeraire, it is easy to show that real net domestic product, Y(t), in this economy should read as:

$$Y(t) = C(t) + dS(t) / dt + (U_S / U_C)S(t) \qquad (1)$$

In equation (1), U_S and U_C are, respectively, the marginal aggregate well-being of the resource stock and consumption flow. We have earlier commented on the second term on the right hand side of (1) - the depreciation of environmental capital. It is the final term I am alluding to now. If the stock is directly beneficial (as with the current stock of the ozone layer), U_S is positive. If it is damaging (as with atmospheric pollution), U_S is negative.[26] In the latter case the final term in equation (1) is negative. Once again, neglecting environmental resources in national accounting would lead to an overestimation of aggregate well-being.[27]

I am of course using the measurement of real net domestic product merely as a prop on which to hang a number of issues concerning public policy. Appropriate criteria for public investment, and the public screening of private investment,

are intrinsically related to the correct way of measuring real net domestic product. They hang together through a network of accounting prices. Optimal investment criteria are merely a way of ensuring that real net domestic product at each instant is maximised. And this in turn is a means of ensuring that the economic path which is followed indeed maximises the present discounted value of the flow of aggregate well-being.[28] While we ignore resource accounting in our aggregate reporting of economies, we overlook as well including them in the evaluation of investment projects. At an analytical level this amounts to regarding resource stocks as valueless. They are regarded as free. In this article I have tried to trace a chain of implications this has on biases in resource use and resource accounting.

IX Inadequate Incentives for Obtaining Information

In fact there is another implication of this, equally grave, and one which I hope will finally justify my choice of starting point in this article: the non-existence of generalised markets for environmental resources. It is the implied absence of private incentives for obtaining information about resource stocks and the technology of resource regeneration, or in other words the ecology of the matter. It is remarkable how little we know of things that are of such long run interest, remarkable not because we can't offer an explanation for why we don't know - I have just provided it - but because of the extent of our ignorance. Often enough, the data one sees, when scrutinised, are merely

anecdotal, no more than pure guesses. As noted earlier, there are a number of countries which have no reasonable estimates of the extent of their forest cover, soil losses, water evaporation rates and so on. Public knowledge of ecological processes is usually negligible. I am thinking here of the functional, or instrumental value of such knowledge. I am thinking of knowledge of ecological processes on par with knowledge of technological transformation possibilities. There is a strong case for the public acquisition of such knowledge, because private incentives are particularly dull in this field. If the farmers in the lowlands can claim no compensation from the upland timber merchant, neither party has an incentive to discover the functional relation between deforestation and soil erosion. These massive uncertainties are real, and a great deal in excess of what they should be.

At a more general level, the direction of technological change is biased on account of all this. When environmental resources are free, there is absolutely no incentive to economise in their use. Technological innovations which are profligate with them look profitable, certainly more so than they ought to look. Over time, an entire sequence of resource-intensive technologies is thus installed. Add to all this the fact that there are often strong learning-by-doing and learning-by-using, even at the stage of research and development, and we arrive at a depressing conclusion: it may require a big push to move societies away from their current profligacy in the use of environmental resources. We may well have got locked into bad habits, not only as consumers and

manufacturers, but also as scientists and technologists. In the meantime, a move towards a more appropriate set of price signals is clearly the right one.

Appendix

In the text (Sections II and IV), we presented an informal account of how co-operation may be sustained over time by means of norms of conduct. A social norm is a behaviour strategy. The critical point in the exercise is to show that there is no need for an outside agency to enforce the norms, and thus to assure co-operation. We have therefore to show that co-operation can be self-enforcing if appropriate norms are followed. (If the strategy needed outside enforcement, e.g. the law courts, it wouldn't be a social norm, it would be something else.)

In this Appendix I shall provide a formal account of this by means of a very special example, that of a two person, repeated game. Specifically, I shall study the two person, repeated Prisoners' Dilemma Game, and I shall develop one type of norms. (There are other norms that can sustain the same co-operative outcome.) I begin by describing their dilemma when the prisoners face each other only once.

There are two agents, 1 and 2. They are generically labelled i and j. Thus, i,j = 1,2. Agent i has two strategies to choose from, A(i) and B(i). The payoff-matrix is given below. Agent 1 chooses row and agent 2 chooses column. The first number in each box is the payoff to player 1, the second to player 2. I assume throughout that the game is common knowledge. (See e.g. Binmore and Dasgupta, 1986; Aumann, 1987, for expositions of this.) Plainly, the game has a unique non

co-operative (Nash) equilibrium outcome (10,10). In fact, (B(1),B(2)), which supports the equilibrium, is a pair of dominant strategies. But the equilibrium is sub-optimal: both parties would be better off were they to choose the pair (A(1),A(2)). We now assume that the parties do not have access to any co-operative infrastructure which would enable them to enforce the choice of the strategy pair (A(1),A(2)).[29] Thus, (B(1),B(2)) will prevail. All this is well known.

1 \ 2	A(2)	B(2)
A(1)	(25,25)	(6,30)
B(1)	(30,6)	(10,10)

In what follows, we call the Prisoners' Dilemma just analysed the stage game, and we assume that this stage game will be repeated.

It is an easy matter to confirm that if the stage game is to be repeated only a finite number of periods, and if this number is common knowledge, the unique non co-operative outcome will be the repeated play of (B(1),B(2)). The players are thus locked in a Prisoners' Dilemma even in this case.[30]

The interesting case is therefore one where the stage game is to be repeated ad infinitum and where this is common

knowledge. The banal observation, that people are mortal, doesn't provide an argument against this hypothesis. The point in studying an infinitely repeated stage game is to avoid having the players use the final date of play as an anchor from which to work backwards. Discounting future payoffs is a way of introducing uncertainty about the actual duration of the play: the higher the discount rate, the lower the weight players give to future payoffs relative to present ones. Discounting is a way of capturing in an analytical model the fact that the actors know that play in all probability will not go on forever, but that neither knows for sure when the game will terminate.[31] We suppose for simplicity of exposition that both players discount their future payoffs at a constant, positive rate, r.

Individual strategies can be extremely complicated in the repeated Prisoners' Dilemma game. A strategy is now a plan of action at each possible contingency. To be precise, choice of an action by either party at date T can be made to depend on how the game has been played until the previous period T-1. We are interested in checking whether an indefinite sequence of (25,25) can be realised as a non co-operative equilibrium outcome by tacit co-operation; that is, where the policing is done by the players themselves and no co-operative infrastructure, such as government, is invoked.

Consider the following strategy for player i (i=1,2), which I shall call strategy Z:

Z: Play A(i) in the first period, and continue to play A(i) so long as the other player, j, plays A(j). Switch to B(i) the period following the first time j plays B(j), and play B(i) thereafter.[32]

We want to locate conditions under which it is in each party's interest to choose Z were the other to choose Z. In other words, we want to locate conditions under which (Z,Z) is a non co-operative (Nash) equilibrium of the infinitely repeated Prisoners' Dilemma game. Notice that if both parties play Z, the outcome to each is the infinite payoff sequence (25,25,...).

Time is discrete. Play begins at t=0. If both parties choose Z, the present discounted value of the flow of payoffs to each is:

$$25 + 25/(1+r) + 25/(1+r)^2 + \ldots = 25(1+r)/r \qquad (A4.1)$$

We wish to locate conditions under which it does not pay either party to deviate from Z, given that the other is playing Z.

Towards this, consider an alternative strategy for, say, player 1 which consists, among other things, of playing A(1) until date T-1, and then switching to B(1) at T.[33] We are assuming that 1 is playing against strategy Z. We can therefore conclude that it will be in his interest to switch permanently to B(1) once he has played B(1). Thus, if it is

ever in 1's interest to switch to B(1), it is in his interest to play B(1) thereafter. Now notice that *if* 1 plans to switch to B(1) at T, and *if* the plan is credible, it will be in 1's interest to switch to B(1) at T *when* T *arrives*. But at T, T *is* the present; it is no longer the future. It follows that, without loss of generality we may as well assume that T=0. In other words, we may as well assume that 1 plays the sequence (B(1),B(1),...) against 2's choice of Z. We wish to see if it is in 1's interest to do so.

Now if 1 were to play an infinite sequence of B(1)s against 2's play of Z, his payoff sequence will be (30,10,10,10,...). And the present discounted value of this stream is:

$$30 + 10/(1+r) + 10/(1+r)^2 + \ldots = 30 + 10/r \qquad \text{(A4.2)}$$

We may conclude that it is in 1's interest to play Z against 2's choice of Z if expression (A4.1) is at least as large as expression (A4.2). It follows that for (Z,Z) to be an equilibrium pair of strategies in the infinitely repeated Prisoners' Dilemma game, we must have

$$25(1+r)/r \geq 30 + 10/r,$$

or,

$$r \leq 3 = 300\%.$$

Stating matters more generally, tacit co-operation can be self-enforcing in an infinitely repeated Prisoners' Dilemma game if neither party discounts future payoffs at too high a

rate. In our specific example, if the parties discount at a rate in excess of 300%, (Z,Z) is not self-enforcing. It is not a non co-operative equilibrium pair of strategies.

All this is congenial to intuition. There is a one-period gain to player i in reneging and playing B(i) forever against Z. The gain is 30-25=5. Set against this is a loss of 25-10=15 in each period starting the period after the first deviation. If i is myopic he will renege. If he is not, he won't.

We should note how this analysis provides a reductionist explanation for such notions as "custom," "codes of conduct," "social norm," "social sanctions," and so forth. However, we should also note that there are many possible "norms" for sustaining the mutually beneficial, co-operative outcome. The strategy we have studied in this Appendix is unforgiving, in that even one deviation (that is, one lapse) on the part of a person is met with eternal punishment. The norm lacks compassion. But it has analytical appeal. It allows us to say that, in the numerical example at hand, were the parties to discount future payoffs at a rate in excess of 300%, no social norm could take hold.

How do we know this? We know this because Z inflicts the severest possible punishment for a single deviation. Any other norm would therefore inflict less severe punishment. It follows that the cost borne by a person for deviating once is less under any other norm. But the benefit remains at 5 for the period at which the norm-breaker breaks the norm. We can

conclude then that if r exceeds 300% no norm can sustain an indefinite play of (A(1),A(2)).

An alternative social norm, which we called conformism, was outlined in Section II. We formalise it now, and call it strategy X.

X: At any date, choose A(i) if and only if the other party had "conformed" at the previous date, where "conformism" at the first date is defined as the play of A(i), i=1,2.

From this definition we can, by recursion, calculate what action is required under X at any date. We now wish to find the critical discount rate for this norm.

If, say, 2 were to play X, then were 1 to deviate from X at any date, his gain would be 5 at that date. Now, we have already noted that the maximum loss he needs incur for this deviation is 15 at the next date. It follows that he will deviate if

$$5 - 15/(1+r) > 0,$$

or,
$$r > 2 = 200\%. \qquad \text{(A4.3)}$$

We conclude that if (A4.3) holds, then X is not a viable social norm. We can also show that any set of deviations can be broken up into a sequence of such simple deviations, and thus conclude that if $r \leq 200\%$ per period, (X,X) is a self-enforcing pair of strategies. X is therefore a viable social

norm if parties discount future payoffs at a rate less than or equal to 200% per period. Note finally, that in this example X can be restated as tit-for-tat.

Footnotes

[1] This neglect has been a persistent phenomenon in British universities. So far as I can tell, courses on resource economics have been regularly on offer in major economics departments in Scandinavia, the United States and Canada over the past 15 years or so. But even there, interest has been muted in recent years.

[2] Simultaneously, a number of non-technical expositions were published. See below in the text for references and sources for further references.

[3] Even Hotelling's great article (Hotelling, 1931) merely scratched the economics of exhaustible resources. The incorporation of substitutability among resources, of technological change and, more generally, the placing of the subject in the context of intertemporal general equilibrium, could be completed only over four decades later.

[4] In the Appendix I give a formal account of this line of argument for a simple two-person model of negotiation.

[5] This assumes that individual actions are publicly observable.

[6] I am ignoring the pressure of population growth on natural resource use in this article. This raises a somewhat wider set of issues, connected not only with common property resources and the absence of an adequate set of capital markets, it is also tied to the fact of the subjugation of women, a phenomenon that is particularly acute in poor countries.

[7] As a half-serious illustration, the reader should ask if it is feasible to engage in bets on people's states of mind.

[8] In a highly original piece of work, Gauthier (1986) argues that even morality should be so regarded.

[9] Formal demonstration of this can be found in many writings. See, e.g. Dasgupta and Heal (Chapter 3).

[10] Kneese and Schultze (1975) is a good early discussion of these issues.

[11] I qualify the term "market" because, as we have seen in Sections II and III, markets should be interpreted in a sense which is wider than the one in which they are commonly understood.

[12] Accounting prices are often called shadow prices. I should add that a commodity, or resource, should be specified not only by its phyical characteristics, date, location and state of nature, as in Debreu (1959), it should also be specified by the agency transacting in it. This is vital for environmental resources. It is important to think of them as named goods. (See Hahn, 1971. See also Arrow, 1971, and Starrett, 1972.) Another way of putting this is to say that these goods are agent-relative. Thus, to give an example, a polluting firm's smoke emission, as it is perceived by the neighbourhood laundry, is a different commodity from that same emission as perceived by the automobile tyre shop in the same neighbourhood.

[13] Ironically, the World Bank was much involved in loans to this agribusiness. It has in recent years reversed its policies, and it is now more sensitive to environmental matters. As we noted in Section I, concern with the environment is an intermittent affair.

[14] For further discussion, see Dasgupta (1982, Chapter 2). Mahar (1988) and Binswanger (1989) have recently compiled a more complete list of macroeconomic policies in Brazil which have encouraged deforestation of the Amazon Basin. Repetto (1988) is a fine survey of the general issue, the effect of government macroeconomic policy on the environment.

[15] There are exceptions of course, such as the ozone layer. It is an exhaustible resource, pure and simple. But nothing is lost in my ignoring these exceptions here.

[16] As noted in the previous footnote, the ozone layer is another example.

[17] For further discussion of the analytical commonality among disparate environmental resource stocks, see Dasgupta (1982).

[18] The analysis which follows was presented originally in Dasgupta and Heal (1979, Chapter 8) and Dasgupta (1982, Chapter 5).

[19] The technical restrictions amount to the requirement that both the set of feasible allocations and the social ordering reflecting aggregate well-being are convex.

[20] Thus, capital gains or losses are not included.

[21] Readers who are mathematically inclined will recognise that the Hamiltonian associated with an intertemporal well-being-optimisation exercise is real net domestic product. This statement requires a mild modification if aggregate well-being

at any given date is strictly concave in consumptions. But it is so mild that we may ignore it.

[22] This leads to the seemingly paradoxical result that net domestic product in a country which lives solely off its exhaustible resources is nil, and it is nil no matter how high the current consumption rate is. See Dasgupta and Heal (1979).

[23] I base this on crude computations that I have made with figures supplied in Repetto et al. (1989).

[24] These are in per capita units.

[25] For simplicity of exposition I shall think of an economy possessing a single, all-purpose good. The reader can easily generalise to the case where there are many kinds of real assets and many consumption goods.

[26] Notice that a commodity can have direct well-being effects which are deleterious even while being indirectly beneficial because of the consumption benefits it provides. Pollutions like pesticides have this property. The model in the text is merely illustrative. A proper model of pollution will lead us to the idea of negative accounting prices. See Dasgupta (1982, Chapter 8).

[27] It is unfortunate that for the most part public debates on environmental matters have concentrated on those resources, such as the atmosphere and tropical forest cover, whose direct well-being effects are unusually difficult to estimate. This usually has the effect of making one think that environmental issues can't really be analysed in the way we analyse other economic issues. Witness the fact that the label "conservation movement" sets in a chain of images in one's mind. As I have tried to elaborate in this essay, a great many environmental problems, of immense importance to human well-being, are ones concerning resources whose direct effects aren't all that difficult to measure. At the very least, research effort ought to concentrate on both classes, and not near-exclusively on the really difficult ones.

[28] Arrow and Kurz (1970) continues to be the most thorough treatment of this topic. But they do not include an account of natural resources.

[29] By a co-operative infrastructure I mean a machinery, such as that provided by the law courts, which can enforce agreements. When such an infrastructure is not present, agreements are not binding. Since (B(1),B(2)) is a pair of dominant strategies, it will unquestionably be chosen in the absence of any possibility of binding agreements. This is the dilemma.

Notice that if the resource costs involved in establishing a co-operative infrastructure were small enough, it would be in the mutual interest of the parties to establish it. The "infrastructure" could then impose a stiff penalty on any party which plays the B strategy. By so imposing a

penalty, the game is changed into one where A(i) becomes the dominant strategy for person i. Notice that in this altered game the penalty is never actually paid! There is no occasion to, because A(i) is now i's dominant strategy. Herein lies the advantage of the co-operative infrastructure. In Chapter II we used this sort of argument in sketching the contractual theory of the State. In recent years it is these ideas from game theory which have been used in articulating social contract theories. See Rawls (1972), Gauthier (1986), Hampton (1986) and Hardin (1988). The more general idea behind the possibility that one can in many circumstances improve one's lot by tying one's hands was a central theme in Schelling (1960).

[30] To confirm this, use the backward induction argument, and have the players reason back from the last period. See Luce and Raiffa (1957).

[31] A constant discount rate implies, of course, that no matter how long the horizon, there is a positive (though vanishingly small) probability that the stage game will be repeated beyond the horizon.

[32] To the best of my knowledge, the efficacy of this strategy was studied first by Friedman (1971). It should be noted that Z is not tit-for-tat, a strategy made famous by Axelrod (1984). Z is not at all forgiving. A single deviation from the (implicitly) agreed play of A(j) by j is punished forever by i when i plays Z. This means of course that after a possible deviation, renegotiation isn't possible. If it is, strategy Z isn't credible. Strategies supporting (25,25) indefinitely, which are invulnerable to renegotiation, have been much studied recently. See Farrell and Maskin (1987), Bernheim and Ray (1987b) and Abreu and Pearce (1989).

[33] If T=0, this means that 1 starts by playing B(1).

References

Abreu, D. (1987), "On the Theory of Infinitely Repeated Games with Discounting," Econometrica, 56.

Abreu, D. and Pearce, D. (1989), "A Perspective on Renegotiation in Repeated Games," mimeo., Hoover Institution, Stanford.

Agarwal, A. et al. (1982, 1986), The State of India's Environment, New Delhi, Centre for Science and Environment.

Arrow, K.J. (1971), "Political and Economic Estimation of Social Effects of Externalities," in M. Intriligator ed., Frontiers of Quantitative Economics, Vol. 1, Amsterdam, North Holland.

Arrow, K.J. and Kurz, M. (1970), Public Investment, the Rate of Return and Optimal Fiscal Policy, Baltimore, Johns Hopkins University Press.

Arrow, K.J. and Fisher, A. (1974), "Environmental Preservation, Uncertainty, and Irreversibility," Quarterly Journal of Economics, 88.

Aumann, R. (1987), "Correlated Equilibrium as an Expression of Bayesian Rationality," Econometrica, 55.

Axelrod, R. (1984), The Evolution of Cooperation, New York, Basic Books.

Barrett, S.A. (1989), Economic Growth and Environmental Conservation, PhD Dissertation, London School of Economics.

Baumol, W. and Oates, W. (1975), The Theory of Environmental Policy, Englewood Cliffs, Prentice Hall.

Bernheim, B.C. and Ray, D. (1987), "Collective Dynamic Consistency in Repeated Games," mimeo., Department of Economics, Stanford University.

Binmore, K. and Dasgupta, P. (1986), "Introduction," in K. Binmore and P. Dasgupta eds., Economic Organizations as Games, Oxford, Basil Blackwell.

Binswanger, H. (1989), "Brazilian Policies that Encourage Deforestation in the Amazon," World Bank Environment Department Paper No. 16.

Brown, G. and C.B. McGuire (1967), "A Socially Optimal Pricing Policy for a Public Water Agency," Water Resources Research, 3.

Clark, C.W. (1976), Mathematical Bioeconomics: The Optimal Management of Renewable Resources, New York, John Wiley.

Coase, R. (1960), "The Problem of Social Cost," Journal of Law and Economics, 3.

Costa, G. (1987), "The Overlapping Generations Economy as a Non-Cooperative Game," Quarto Convegno di Teorio Giochi e Applicazioni, Bergano.

Dales, J.H. (1968), Pollution, Property and Prices, Toronto, Toronto University Press.

Dasgupta, P. (1982), The Control of Resources, Oxford, Basil Blackwell.

Dasgupta, P., Hammond, P. and Maskin, E. (1980), "On Imperfect Information and Optimal Pollution Control," Review of Economic Studies, 47.

Dasgupta, P. and Heal, G. (1979), Economic Theory and Exhaustible Resources, Cambridge, Cambridge University Press.

Dasgupta, P. and Weale, M. (1989), "On International Comparisons of Well-Being," mimeo., University of Cambridge.

Debreu, G. (1959), Theory of Value, New York, John Wiley.

Farrell, J. and Maskin, E. (1987), "Renegotiation in Repeated Games," mimeo., Department of Economics, University of California, Berkeley.

Feder, E. (1977), "Agribusiness and the Elimination of Latin America's Rural Proletariat," World Development, 5.

Feder, E. (1979), "Agricultural Resources in Underdeveloped Countries: Competition between Man and Animal," Economic and Political Weekly, 14.

Gauthier, D. (1986), Morals by Agreement, Oxford, Clarendon Press.

Hahn, F. (1971), "Equilibrium with Transaction Costs," Econometrica, 39.

Hampton, J. (1986), Hobbes and the Social Contract Tradition, Cambridge, Cambridge University Press.

Hardin, G. (1968), "The Tragedy of the Commons," Science, 162.

Hardin, R. (1988), "Reason and the Limits of Justice," Chicago, Chicago University Press.

Hartwick, J. and Olewiler, N. (1986), The Economics of Natural Resource Use, New York, Harper & Row.

Hotelling, H. (1931), "The Economics of Exhaustible Resources," Journal of Political Economy, 39.

IIED/WRI (1987), World Resources 1987, New York, Basic Books.

Kneese, A. (1964), The Economics of Regional Water Quality Management, Baltimore, Johns Hopkins University Press.

Kneese, A. and Schultze, C. (1975), Pollution, Prices and Public Policy, Washington, D.C., Brookings Institution.

Krutilla, J. (1967), "Conservation Reconsidered," American Economic Review, 57.

Krutilla, J. and Fisher, A. (1975), The Economics of Natural Environments: Studies in the Valuation of Commodity and Amenity Resources, Baltimore, Johns Hopkins University Press.

Lind, R. ed. (1982), Discounting for Time and Risk in Energy Policy, Baltimore, Johns Hopkins University Press.

Luce, R.D. and Raiffa, H. (1957), Games and Decisions, New York, John Wiley.

Mahar, D. (1988), "Government Policies and Deforestation in Brazil's Amazon Region," World Bank Environment Department Working Paper No. 7.

Mäler, K.-G. (1974), Environmental Economics: A Theoretical Enquiry, Baltimore, Johns Hopkins University Press.

Mäler, K.-G. and Wyzga, R.E. (1976), Economic Measurement of Environmental Damage, Paris, OECD.

Meade, J.E. (1973), The Theory of Externalities, Geneva, Institute Universitaire de Hautes Etudes Internationales.

Pigou, A.C. (1920), The Economics of Welfare, London, Macmillan.

Repetto, R. (1988), "Economic Policy Reform for Natural Resource Conservation," World Bank Environment Department Working Paper No. 4.

Repetto, R. et al. (1989), Wasting Assets: Natural Resources in the National Income Accounts, Washington, D.C., World Resources Institute.

Samuelson, P.A. (1961), "The Evaluation of 'Social Income': Capital Formation and Wealth," in F. Lutz and D. Hague, eds., The Theory of Capital, London, Macmillan.

Schelling, T. (1960), The Strategy of Conflict, Cambridge, MA, Harvard University Press.

Starrett, D. (1972), "Fundamental Non-Convexities in the Theory of Externalities," Journal of Economic Theory, 4.

Tietenberg, T. (1980), "Transferable Discharge Permits and the Control of Stationary Source Air Pollution: A Survey and Synthesis," Land Economics, 56.

Tietenberg, T. (1988), Environmental and Natural Resource Economics, Glenview, Ill., Scott, Foresman & Co., 2nd Edition.

Ulph, A. (1989), "A Review of Books on Resource and Environmental Economics," Bulletin of Economic Research, 42.

Weitzman, M. (1976), "Welfare Significance of National Product in a Dynamic Economy," Quarterly Journal of Economics, 90.

Weale, M. (1989), "Environmental Resources and National Income," mimeo., Department of Economics, University of Cambridge.

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