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Preface

The Possibility of Cooperation is, I hope, much more than the preceding statement might suggest, 'a new edition of *Anarchy and Cooperation*'. The chapter dealing with the political theories of Hobbes and Hume is the only one to survive intact, though the short chapter on altruism and the rather informal Epilogue contain much of the corresponding chapters of the earlier book. All the rest has been substantially re-cast. Amongst other things, I have devoted much more of the book to the theory of collective action, which in the years since writing *Anarchy and Cooperation* I have come to see as absolutely fundamental to the study of politics and history, and in particular I have devoted more space to the theory of conditional cooperation in supergames and at the same time tried to make the formal treatment of this subject more accessible to the non-mathematical reader than it was before.

Anarchy and Cooperation was constructed as a critique of the liberal theory of the state, according to which the state is necessary because people, being rational, will not voluntarily cooperate to provide themselves with public goods, in particular the basic public goods of social order and defence. At the heart of this critique was a study of the Prisoners' Dilemma supergame, for it had been (as it still is) widely assumed that the problem of public goods provision, or 'the collective action problem' more generally, has the form of a Prisoners' Dilemma. So in the central chapters of *Anarchy and Cooperation* I wanted to question whether the Prisoners' Dilemma game was the correct representation of preferences in public goods interactions and then, assuming that it was, to examine the prospects for voluntary cooperation in this game. At that time there had been little theoretical study of the iterated Prisoners' Dilemma, especially in its N-person form. Yet it seemed obvious to me that the one-shot game had little to do with anything of importance in the real world and that most problems of public goods interaction and of collective action generally had more than two players. Accordingly, I devoted the central chapter of *Anarchy and Cooperation* to an analysis of the two-person and N-person Prisoners' Dilemma supergames (in which the basic games are played an indefinite number of times).

This purely formal treatment of collective action and the Prisoners' Dilemma supergame could be – and generally was – read and used independently of the critique of the liberal theory of the state. In this new edition, the critique stands, though parts of the old final chapter ('Anarchy') have been rewritten and are offered less confidently in the Epilogue. (Further doubts about 'anarchy' have also crept into my *Community, Anarchy and Liberty*, which is in some respects a companion piece to this book, and some day I hope to publish a third volume giving a fuller and more historical account of the state.) But, as before, the analysis of collective action and the Prisoners' Dilemma supergame can be read – and assessed – independently of the critique, and this part of the book has been substantially recast and extended. Chapter 3 of the old book – the central chapter dealing with the Prisoners' Dilemma supergame – has been almost completely rewritten: the material has been re-organized, some of the arguments have been modified and extended, and several new sections have been added. I have endeavoured to make the analysis more accessible to readers with little training in mathematics, and in pursuing this end I found that I could derive the same results – and indeed strengthen and extend them – using far less algebra. The new treatment is split between two chapters. To the first of these, dealing with the two-person supergame, I have added amongst other things a brief section commenting critically on related work by Robert Axelrod and Russell Hardin published since *Anarchy and Cooperation* appeared. All the results in this chapter which formerly gave only necessary conditions for various equilibria now provide conditions which are both necessary and sufficient. To the second of these chapters, dealing with the N-person supergame, I have added, partly in response to a critical point raised by several readers of *Anarchy and Cooperation*, a section which shows how this game can give rise to a Chicken game (thus introducing a troublesome indeterminacy into the analysis of the N-person case).

The brief account of the effects of altruism on behaviour in Prisoners' Dilemma games has also been pruned of some unnecessary algebra. Removing much of the mathematics from this chapter and from the treatment of the Prisoners' Dilemma supergame has made redundant the old chapter 5, which provided an informal summary of the mathematical parts of the book, and I have therefore removed it.

Chapter 2 is almost entirely new. Amongst other things it develops an argument to the effect that in public goods problems individual preferences at any point in time are not necessarily those of a Prisoners' Dilemma; that in fact many interesting public goods problems, both two-person and N-person, are better represented by Assurance and Chicken games; and that where individuals can choose from a *continuous* range of strategies their preferences are quite likely to be those of a Chicken-like game or of a hybrid between a Chicken and an Assurance game. In all of these cases, arguably, *some* cooperation is more likely than in the case of a Prisoners' Dilemma, even when the game is played only once. Chicken emerges from this discussion, and from the account in chapter 4 of the N-person Prisoners' Dilemma supergame, as an important game. A little analysis of this neglected game is offered here, but much more needs to be done.

Much of chapter 1 is also new (i.e., not to be found in *Anarchy and Cooperation*). Partly in order to make the book a little more self-contained, I have given in the opening section a fuller summary of Olson's 'logic of collective action' and in particular his important argument that the larger a group is, the less likely are its members to cooperate voluntarily in the provision of a public good. I agree with those writers who have shown that this 'size' effect is not always present, but I want also to argue that not too much weight should be attached to any of these 'size' arguments – Olson's or his critics' – because the *model* from which they derive, being entirely static, is an unrealistic representation of almost all problems of public goods provision, which are of course typically recurring. In a dynamical formulation, but not of course in a static one, there is the possibility of *conditional* cooperation; and I would argue that the 'size' effect which should be taken most seriously is the increased difficulty of conditional cooperation as group size increases.

Many of the arguments in this book apply not just to problems of public goods provision but to 'collective action problems', a much larger category. So I added to chapter 1 a brief attempt to characterize this category. I have also added a new section which both characterizes the range of possible solutions to collective action problems and examines the particular claims that such problems can be solved by political entrepreneurs, by the establishment of property rights and by norms.

I have made no attempt to provide a comprehensive survey of developments in the study of public goods, collective action and supergames that have occurred since the publication of *Anarchy and Cooperation*. Although I have commented briefly on the most closely related work (such as that of Hardin and Axelrod) and have made a number of excisions and revisions that were prompted by some of these developments, I have not, for example, reviewed either the extensive recent theoretical work of economists and game theorists on supergames or the even more extensive experimental work of psychologists, sociologists and others on iterated Prisoners' Dilemmas. I still believe that, if problems of public goods provision or other collective action problems are to be modelled as iterated games, then the appropriate model is a game iterated an indefinite number of times in which players discount future payoffs. But although most economists seem to share this view, most of the recent *mathematical* work on supergames treats either *finitely* iterated games or infinite supergames *without* discounting. I have, however, provided some references to this work for those wishing to pursue it. As for the vast experimental literature, I remain unpersuaded that its results can tell us much about the real world beyond the experiments. There are two general problems with this literature. First, the experiments are of short duration relative to the time span of the processes in the real world they are supposed to simulate; so discounting plays no role in the experiments, while in the real world it is crucial. Second, the experimental payoffs are generally too small to elicit rational behaviour. It is therefore not surprising that these experiments yield such mixed results, with some studies finding significant free riding and 'size' effects and others not.

Much more promising, in my view, are *historical* studies of collective action. I have not tried to summarize such studies, which are thin on the ground, for the best of them are still in progress and yet to be published, but a good example of the sort of thing I have in mind is John Bowman's forthcoming study of collective action amongst capitalists (based on his

doctoral dissertation, 'Economic competition and collective action: the politics of market organization in the bituminous coal industry, 1880–1940', University of Chicago, 1984), which amongst other things uses the theory of conditional cooperation in Prisoners' Dilemma supergames to scrutinize the historical data. Arduous though it is compared with experimental work, this, it seems to me, is the kind of empirical work we need more of.

Anarchy and Cooperation owed much to the kind help of Brian Barry, Alan Carling, Ian Grant and Michael Nicholson, who commented extensively on the manuscript. If I had heeded more of Brian Barry's advice at that time, much of the rewriting that has gone into this new version would not have been necessary. For their help in various ways in the preparation of this edition I should like also to thank Jon Elster, who suggested it; Russell Hardin, who in conversation has helped me to clarify a number of points; Dawn Rossit, who as my research assistant in Seattle in the autumn of 1985 gave me valuable help in connection with the discussion of property rights in chapter 1; and Hugh Ward, who collaborated with me in work on the game of Chicken on which a part of chapter 2 is based. The first edition was written during 1973–74 when I was a Fellow at the Netherlands Institute for Advanced Study, whose staff I would like to thank for their hospitality and help. For freedom to work on this new edition, I am grateful to the University of Essex, and for provision of a research assistant and for general support I would like to thank the chairman of the Department of Political Science at the University of Washington in Seattle.

M.J.T.

1. Introduction: the problem of collective action

The most persuasive justification of the state is founded on the argument that, without it, people would not successfully cooperate in realizing their common interests and in particular would not provide themselves with certain public goods: goods, that is to say, which any member of the public may benefit from, whether or not he or she contributes in any way to their provision. The most appealing version of this justification would confine the argument about voluntary cooperation to what are supposed to be the most fundamental public goods: goods (or services) which are thought to be preconditions of the pursuit and attainment of all other valued ends, including less basic public goods, and are therefore desired by *everyone* within the jurisdiction of the state in question.

The Possibility of Cooperation is a critique of this justification of the state, and the heart of the critique (chapters 2–4 below) is a detailed study of cooperation in the absence of the state and of other kinds of coercion. (The arguments about public goods provision and the theory of cooperation which make up these chapters can be read – and assessed – independently of the critique of the Hobbesian justification of the state.)

Hobbes's *Leviathan* was the first full expression of this way of justifying the state. The public goods with which he was principally concerned were social order – domestic peace and security – and defence against foreign aggression. Without these, very little else that was worth having could be had. Without internal and external security, there would be not only actual violence but such pervasive uncertainty as to undermine the incentive to invest resources in any projects with delayed returns. But although everyone would prefer the condition of peace and security that mutual restraint ensures to the 'war of all against all' that is the result of everyone pursuing his own interests without restraint, no individual has the incentive, in the absence of the state, to restrain himself. It is therefore rational, says Hobbes, for everyone to institute a government with sufficient power to ensure that everybody keeps the peace.[1]

Many writers who came after Hobbes, including some who professed no sympathy with what they took to be Hobbes's ideas, have taken over the core of his case for the state. Most economists who nowadays write about public goods believe that the failure of people to provide themselves voluntarily with these goods constitutes at least a *prima facie* case for state activity, and most of them presume that the state is the *only* means for remedying this failure.[2] (For nearly all the rest, the remedy is to establish or extend private property rights. I'll comment briefly on this view later in the chapter.)

Of course, many people believe that the state can be justified on further grounds and that it has functions other than that of providing public goods. Certainly, modern states do more than provide such goods. However, the justification I wish to criticize here is common to the arguments of nearly all those who believe that the state is necessary. Its persuasiveness lies in the fact that the state, on this view, exists to further *common* interests, to do what *everybody* wants done. Other arguments – for example, that income redistribution is desirable and can be brought about only through the intervention of the state – do not appeal to common interests, not, at any rate, in an obvious or uncontroversial way.

In recent years, this argument about the necessity of the state has found new supporters amongst those concerned with the degradation of the environment, the depletion of non-renewable resources and rapid population growth. According to them, people will not *voluntarily* refrain from discharging untreated wastes into rivers and lakes, from hunting whales and other species threatened with extinction, from having 'too many children', and so on. Only powerful state action, they say, can solve or avert these problems, which are the consequence of failures to provide public goods (and more generally 'non-excludable' goods – about which more later). For many environmentalists, some of these public goods are at least as fundamental as peace and security were for Hobbes. Continued failure to provide them will eventually result in ecological catastrophe. Without them, the life of man will not just be 'solitary, poore, nasty, brutish, and short'; it will be impossible.[3]

There have of course been other responses to the environmental crisis. In particular, some writers, who probably did not think of themselves as anarchists, have come to embrace essentially communitarian anarchist ideas. However, of those who desire on ecological grounds the goal of a social organization along communitarian anarchist lines, there are very few who believe that a transition to such a society can be made without extensive state activity.[4]

As for the members of governments themselves, and indeed of most political parties, especially in industrialized countries, they generally do not recognize that there is or will be an environmental crisis and they believe, not unnaturally, that pollution and resource depletion are problems which can be adequately dealt with by minor modifications within the present institutional framework of whatever country they happen to live in.[5] Generally speaking, the proposed modifications involve an extension of state activity, in the form of state-enforced pollution standards and resource depletion quotas, taxes on industrial pollution, government subsidies and tax credits for the development of pollution control technology, and so on. Most economists who have written on problems of pollution and resource depletion have also confined their discussions to 'solutions' of this sort, or otherwise have recommended the extension of private property rights.

Much of what I shall have to say in this book will in fact apply, not just to the voluntary provision of public goods but to 'collective action problems', a much larger category. The defining characteristic of a collective action problem, as I shall use this expression, is very roughly that rational egoists are unlikely to succeed in cooperating to promote their common interests. (I will clarify this in a later section.) On this account, as we shall see, the category of collective action problems includes many but not all public goods problems. There is, in particular, a very important class of collective action problems which arise in connection with the use of resources to which there is open access – resources, that is, which nobody is prevented from using. These resources need not be public goods, as I will define them shortly. Garrett Hardin's well-known 'tragedy of the commons' concerns resources of this kind.[6]

Hardin asks us to imagine a common, a pasture open to all. The village herdsmen keep animals on the common. Each herdsman is assumed to seek to maximize his own gain. As long as the total number of animals is below the carrying capacity of the common, a herdsman can add an animal to his herd without affecting the amount of grazing of any of the animals, including his own. But beyond this point, the 'tragedy of the commons' is set in motion. Asking himself now whether he should add another animal to his herd, he sees that this entails for him a gain and a loss: on the one hand, he obtains the benefit from this animal's yield (milk, meat or whatever); on the other hand, the yield of each of his animals is reduced because there is now overgrazing. The benefit obtained from the additional animal accrues entirely to the herdsman. The effect of overgrazing, on the other hand, is shared by all the herdsmen; every one of them suffers a slight loss. Thus, says Hardin, the benefit to the herdsman who adds the animal is greater than *his* loss. He therefore adds an animal to the common. For the same reason, he finds that it pays him to add a second animal, and a third, a fourth and so on. The same is true for each of the other herdsmen. The result is that the herdsmen collectively bring about a situation in which each of them derives less benefit from his herd than he did before the carrying capacity of the common was exceeded. The process of adding animals may indeed continue until the ability of the common to support livestock collapses entirely.

For similar reasons, many species of fish and whales are hunted without limit and in some cases brought close to extinction: the oceans are like a great common. For similar reasons, too, lakes and rivers are polluted, since each polluter finds that the costs of treating his wastes before discharging them or of modifying his product are too great in comparison with what he suffers from the decline in the quality of the air or water caused by his effluent.

In all these situations, we can say that it is in every individual's interest not to restrain himself (from adding animals to the common, polluting the lake, etc.) but the result of everyone acting without restraint is a state of affairs in which every individual is less well off than he would be if everybody restrained themselves.

In such situations, we might expect people to make an agreement in which they all promised to restrain themselves. However, in the absence of the state (or some other form of coercion), no individual has any greater incentive to abide by the agreement than he had to restrain himself before the agreement was made.

I shall later question whether grazing commons – such as those which were part of the European open-field systems or those which were once widespread in pastoral economies – do in fact typically have open access. But certainly there are many such resources to be found in other contexts.

The recent history of the whale 'fisheries' provides a sad example. During the 1950s and 1960s, unlimited killing of blue and fin-back whales, which are the biggest, brought these two species close to extinction. When stocks of blues and fin-backs became very low, the other large species were hunted without limit. In each case the annual harvest far exceeded the maximum sustainable yield, that is, the maximum number which can be replaced each year through reproduction (and the whale hunters knew this). The profitability of whaling declined, and most of the former whaling countries were obliged one by one to leave the industry (so that, by 1968, there were only two countries, Japan and the USSR, left in the field). It seems fairly certain that if it were not for the diminished profits from hunting a sparse population, the blue whale and other species would in fact have been hunted to extinction. After the Second World War, the International Whaling Commission was set up by the seventeen countries who were then interested in whaling and was charged with regulating harvests and ensuring the survival of threatened species. Until very recently, this Commission, which has no powers of enforcement, has not been very successful. Its members were often unable to agree to impose the quotas recommended by biologists, or else they could agree only to limits in excess of these recommendations; and when the Commission did decide either to limit harvests or to protect a species completely, the agreement was not always observed by every country.[7]

The provision of public and other non-excludable goods

Before embarking on a detailed analysis, we need to define a little more carefully some of the terms that have already been used, and in particular the notions of a 'public good' and a 'collective action problem'.

I shall say that a good or service is a *public good* (or collective good) if it is in some degree indivisible and non-excludable. A good is said to exhibit perfect *indivisibility* or *jointness of supply* (with respect to a given set of individuals, or public) if, once produced, any given unit can be made available to every member of the public, or equivalently if any individual's consumption or use of the good does not reduce the amount available to others.[8] A good is said to exhibit *non-excludability* (with respect to some group) if it is impossible to prevent individual members of the group from consuming it or if such exclusion is 'prohibitively costly' (a notion whose precise definition matters for some purposes but not for mine here).

A perfectly *divisible* good is one that can be divided between individuals. Once any part of it is appropriated by any individual, the same part cannot be made available to others; and once any unit of it is consumed by any individual, the amount available for consumption by others is reduced by the whole of that unit. A loaf of bread and a pot of honey are examples of perfectly divisible goods. A good which is perfectly divisible is called a *private good*. Thus, in order to be public, a good must exhibit some degree of indivisibility or jointness.[9]

A good may be indivisible yet excludable. A road or bridge or park can be provided in this form. Once supplied to one individual, it *can* be made available to others, but it need not be, for it is possible and may not be prohibitively costly to exclude particular individuals. Hence tolls and admission charges can be imposed. Goods like these can be provided in an excludable or non-excludable mode. Indivisibility, then, does not imply non-excludability. Furthermore, divisibility does not entail excludability, although important examples of non-excludable, divisible goods are not easy to come by: economists have suggested such examples as a garden of flowers, whose nectar can be appropriated by individual bees but particular bees cannot be excluded from consumption.

If an individual is not excluded from consumption or use of a public good, it is possible for him to be a *free rider* on the efforts of others, that is, he can consume or use the public good that is provided by others (unless of course everyone else tries to free-ride as well!). Whether or not he will in fact be a free rider is something we have to examine.

Free rider problems (and hence, as we shall see, collective action problems) can arise where there is non-excludability but not indivisibility. In fact non-excludability (or *de facto* non-exclusion) and divisibility (at least in principle) characterize Garrett Hardin's 'commons', or any resource to which there is open access, such as a common fishing ground, a common underground reservoir of oil or water, or the open range on the Great Plains before any property rights were established (including the 'common property' rights that the cattlemen tried to maintain when they formed associations to regulate access and use). I will have a little more to say about such resources in a later section. With some of them, exclusion is possible and economically feasible, but whether or not there is in fact exclusion, consumption or use by one individual reduces the amount available to others and any cutting back on consumption by one individual allows others to consume more.

Most, if not all, public goods interactions are characterized by a certain degree of *rivalness*. It is normally said that a good is *rival* to the extent that the consumption of a unit of the good by one individual decreases the *benefits* to others who consume that same unit. Obviously, in the case of a perfectly divisible good the consumption of a particular unit prevents any other individual from consuming it at all, so that there can be no question of his benefiting from consumption. In this case we might say that the good is perfectly rival. But non-rivalness is not the same thing as indivisibility, as some writers like to say, even though they are usually closely associated. Where there is some degree of divisibility, consumption reduces the *amount* available to others; but where there is some degree of rivalness, consumption reduces the *benefits* to other consumers. An individual's benefit from consumption may not change at all as the amount available for consumption declines, until some threshold of 'crowding' is reached. In fact, although others' consumption usually *lowers* an individual's utility – as is normally the case with congested parks, beaches and roads and with various forms of pollution – some individuals' utilities may *rise* as the number of other consumers increases, at least up to a point; they may, for example, prefer a semi-crowded beach or park to an empty one. This brings out the point that rivalness, unlike indivivisibility, is strictly speaking a property of individuals (or of their utility functions), not of the goods themselves.

Rivalness is clearly important in the analysis of collective action problems. As we would expect – and as we shall see in the next chapter – it plays a crucial role in the analysis of 'size' effects. For just as the alternatives actually available to an individual must change as the number of people in the group increases if there is some degree of divisibility, so the *utilities* of these alternatives must change with group size if there is rivalness.

I said in an earlier section that social order and national defence are public goods. This needs some qualifying and we are now in a position to do so. National defence can in fact be decomposed (on a first rough cut) into deterrence, which is a pure public good because it is both perfectly indivisible and completely non-excludable, and protection from attack, which is imperfectly indivisible and more or less excludable depending on the form it takes. (And of course the production of the means to these ends produces incidental private goods, including income for shareholders and employees of business firms.)[10] The security of persons and their property which I have taken to be constitutive of social order is similarly the product of a variety of goods and services, which range (in a modern society) from purely private goods like locks and private bodyguards through such services as police forces and law courts to deterrence, which, again, can be purely indivisible – as it would be if the fact that attack was deterred on one individual did not diminish the deterrent effect with respect to other individuals.[11]

Under what circumstances, then, will people cooperate to provide a public good or any non-excludable good which the members of a group have a common interest in providing? The now standard answer to this question (which, however, needs to be qualified, as we shall see) is the one provided by Mancur Olson in his well-known study, *The Logic of Collective Action.* Olson's main contention is that 'the larger a group is, the farther it will fall short of providing an optimal supply of any collective good, and the less likely that it will act to obtain even a minimal amount of such a good. In short, the larger the group, the less likely it will further its common interests.'[12]

There are three arguments in support of this conclusion to be found in Olson's book. Before setting them out, we need some definitions. A group is *privileged* if it pays at least one of its members to provide some amount of the public good unilaterally, that is, to bear the full cost of providing it alone. Any group which is not privileged is said to be *latent.* Where the group is privileged, there is, in Olson's view, a 'presumption' that the public good will be provided; but there should be no such presumption in the case of a latent group. Nevertheless, some latent groups (in Olson's account, which is a little muddy at this point) are sufficiently small that through some sort of strategic interaction amongst their members they may succeed in providing some amount of the public good. (They do not have so many members, says Olson, that an individual contribution to the provision of the public good will go

unnoticed by other members.) Such groups are called *intermediate.* The remaining latent groups are so large that this sort of strategic interaction, depending as it does on individual contributions being 'noticeable', is impossible and an individual will contribute only if there is a *selective incentive* to do so, that is, the individual receives a (private) benefit if and only if he contributes and/or incurs a (private) cost if and only if he fails to contribute. Thus, for example, trade unions, which are founded primarily to provide for their members certain public goods such as higher wages and better working conditions, have also had to offer prospective members sickness, unemployment and dispute benefits and other positive selective incentives, and to operate a 'closed shop' which bars non-members from employment.

In deciding whether or not to contribute or participate, the individual compares the cost to him of making his contribution and the benefit *to him* of the additional amount of the public good *provided as a result of his contribution.* The final italicized phrase encompasses both the public good which he himself directly produces or which is funded by his contribution *and* whatever additional public good is provided by the contributions that *others* may make as a result of his contribution (because their contributions are in some way contingent on his). This second component of his benefit may not be forthcoming, because the required interdependence is absent. It is this interdependence which for Olson characterizes 'intermediate' groups.

Now we can state the three arguments which Olson offers in support of his argument that larger groups are less likely than smaller groups to provide any (or an optimal) amount of the public good.[13]

(i) The larger the group, the smaller is each individual's net benefit from the public good.
(ii) The larger the group, the less the likelihood that it will be privileged or intermediate.
(iii) The larger the group, the greater the 'organization costs' of providing the public good (including the costs of communication and bargaining amongst group members and perhaps the costs of creating and maintaining a formal organization).

The last of these claims is the most straightforward. It is also no doubt empirically true, for very many cases.

The second claim is a little less straightforward. How much support it gives to the argument that a public good is more likely to be provided in smaller groups depends on the reliability of Olson's 'presumption' that the public good will be provided in privileged groups and on how likely it is that collective action will be successful in intermediate groups. Olson says that the outcome of interaction in intermediate groups is 'indeterminate'. As for the 'presumption', it is perhaps appropriate only where there is just one individual who is willing to provide the public good unilaterally (and even then there should be no presumption that an optimal amount of it will be provided). But if two or more individuals are so willing, then there could be strategic interaction amongst them . . . and the outcome of such interaction is indeterminate.[14] (The game amongst these players may be what is known as a Chicken game, which will be discussed in some detail in the next chapter.) The privileged group is therefore in effect a group within which there is an intermediate group, that is, a group with a subgroup whose members interact strategically.

The privileged group, it seems to me, is a special case of a group *with at least one subgroup whose members collectively find it worthwhile to provide some amount of the public good by themselves*, that is, a subgroup such that, if all its members cooperated to provide the public good, each of them would be better off than they would be if none of the public good was provided. Again, this does not guarantee that any of the public good will be provided, since normally there will be strategic interaction amongst the members of the subgroup, and there will be strategic behaviour of a different kind – which may also obstruct provision of the public good – resulting from the coexistence of *several* such subgroups. A group which is 'privileged' in this generalized sense is also, then, a group within which there is at least one 'intermediate' subgroup.

A final point about claim (ii) is that, as Russell Hardin has observed, there is no necessary connection, and probably a very weak correlation, between the size of a group and whether it is privileged (in Olson's or my generalized sense) or intermediate. Privileged groups can be large; groups as small as two can be intermediate or latent.[15]

It is worth emphasizing here parenthetically that it is dangerous to distinguish intermediate and latent groups, as Olson sometimes did and as so many later authors have done, by reference to whether an individual contribution is 'noticeable' or 'perceptible'. Such talk has led a number of writers astray.[16] Individual contributions can be perfectly 'noticeable' in a group which is not privileged and in which there is no

strategic interaction, and which therefore fails (in the absence of selective incentives) to provide any of the public good; the failure arises because each individual's contribution, though 'noticeable', brings too little of the public good to be worth the cost of the contribution.

This leaves the first of Olson's three arguments about the effect of increasing group size. As it stands this claim is undecidable. Before we can assess it, we must know what kind of public good is involved and what is held constant as size varies, for, as Hardin says, it is not possible to increase size while holding *everything* else constant.[17] We should, however, hold as many things as possible constant if we are to isolate a pure *size* effect. Now the individual's net benefit can decrease as group size increases because the costs of providing the public good (excluding the organizational costs) increase or the individual's benefits decrease or both. If it is a pure size effect we are looking for, we should count a cost increase as support for Olson's claim only where such an increase is unavoidable. The individual's benefit, on the other hand, decreases with group size only if there is *imperfect jointness* or some degree of *rivalness* or both. If jointness is less than perfect, that is, there is some 'crowding', then the amount available to an individual decreases as the number of consumers increases. If there is rivalness, then, as size increases, the individual's benefits decrease, whether or not the amount actually available to him decreases. (Normally, rivalness is an effect of imperfect jointness. But the two are analytically distinct, and in practice the effects of rivalness can set in, as group size increases, before the effects of imperfect jointness or literal 'crowding' do.)[18]

Olson's first claim in support of the 'size' effect, then, is not necessarily true. It holds only where costs unavoidably increase with size or where there is imperfect jointness or rivalness or both. Most goods, however, exhibit *some* divisibility, and most public goods interactions exhibit *some* rivalness (which is, recall, a property of individual utility functions rather than directly of the good). That is the theoretical position; in practice, we often want to compare groups which differ not only in size but in so many other particulars that this claim is undecidable because isolating a pure size effect is impossible.

There is a more important reason for not pursuing the issue here. The argument here (following Olson and Hardin) assumes that we can simply subtract costs from benefits. This is generally unrealistic (as Olson himself admits[19]). Preferences should instead be represented by indifference maps. This will be done in chapter 2. Further, Olson's whole analysis is entirely static: the individual is supposed in effect to make just one choice, once and for all, of how much to contribute to the public good. But in the real world, most public goods interactions are dynamical. The choice of whether to contribute and how much to contribute is a recurring one. There is interaction *over time* between different individuals' choices. And the individual's intertemporal preferences (how much he discounts future relative to present benefits) matter. A dynamical analysis is the subject of chapters 3 and 4.

Olson's *model*, then, is rather unrealistic. Accordingly, not too much weight should be attached to conclusions derived from it, including conclusions about the effects of increases in group size. The size effect which I think should be taken most seriously is *the increased difficulty of conditional cooperation* in larger groups. For, as we shall see, in a dynamical analysis the provision of a public good, or collective action more generally, requires that amongst at least some members of the group there is conditional cooperation. Olson is of little help here, since he does not provide (indeed cannot provide, within his static model) an analysis of conditional cooperation or of any other sort of strategic interaction over time.

To round out this brief discussion of Olson's treatment of the problem of collective action, a comment is in order on his assumptions about incentives and individual motivation. Recall that, according to Olson, only a selective incentive will motivate the member of a large latent group (one that is too large to be intermediate) to contribute to the provision of the public good. (If Olson did not think of individual contributions in such groups as being 'imperceptible' or 'infinitesimal', he would perhaps have said: only the *addition* of a selective incentive will make the difference between contribution and non-contribution. For there is no reason why, upon the introduction of selective incentives, the public good benefit to the individual should drop out of his calculation even though it is very small: it is never so small as to be 'infinitesimal'.) In fact, says Olson, the public good lobbying efforts of large groups are *by-products* of organizations which obtain their support by offering selective incentives.[20] But this argument, as several writers have pointed out, though it helps to explain the maintenance of the organization, does not explain its origin.

Now selective incentives can be either positive or negative – providing

a benefit to a contributor or imposing a cost on a non-contributor – and they are limited, in Olson's account, to either 'monetary' or 'economic' incentives and 'social' incentives. The *social* incentives essentially derive from the desire for approbation and the dislike of disapprobation, and work through mechanisms like criticism and shaming by friends and associates. Such incentives are effective only in relatively small groups. Hence, a very large group might yet succeed in providing a public good if it has a *federal* structure, for within the local branches or subgroups social incentives can operate to maintain support. (And I would add: if the local branches are small enough for social incentives to be effective, they are probably small enough for conditional cooperation to be sustained, perhaps with the help of the social incentives. More on this in later chapters.)

There are therefore at most four components in the individual's benefit-cost calculations: (i) the benefit to the individual from the increased amount of the public good provided as a result of his contribution; (ii) the cost of his contribution; (iii) the individual's portion of the costs of organization; and (iv) the 'economic' and 'social' benefits and/or costs which operate as selective incentives.

Olson explicitly excludes other types of incentives, including 'psychological' ones, such as 'the sense of guilt, or the destruction of self-esteem, that occurs when a person feels he has forsaken his moral code'.[21] The important reason why (in any explanatory theory) the range of incentives which are assumed to motivate individuals must be limited – though this is not among the reasons Olson gives for *his* restriction – is that without such a limitation a rational choice theory such as Olson's is liable to become tautologous. Three important kinds of motivation which Olson – in common with nearly all other rational choice theorists – excludes are altruistic motivations (to be discussed in chapter 5), expressive motivations and 'intrinsic' motivation by benefits got in the very act of participating in the provision of the public good as opposed to the benefits which successful provision would bring. The last two give rise to non-instrumental action.[22]

The Prisoners' Dilemma

It has been widely asserted that individual preferences in public goods interactions and in collective action problems generally are (or usually are) those of a Prisoners' Dilemma game.[23] This game is defined as follows.

Suppose that there are just two individuals (or *players*) and that each of them may choose between two courses of action (or *strategies*). The players are labelled 1 and 2 and the strategies C and D. The two players must choose strategies simultaneously, or, equivalently, each player must choose a strategy in ignorance of the other player's choice. A pair of strategies, one for each player, is called a *strategy vector*. Associated with each strategy vector is a *payoff* for each player. The payoffs can be arranged in the form of a *payoff matrix*. The payoff matrix for the two-person Prisoners' Dilemma which will be studied in this book is:

		player 2	
		C	D
player 1	C	x, x	z, y
	D	y, z	w, w

where $y > x > w > z$. Throughout the book, the usual convention is adopted that rows are chosen by player 1, columns by player 2, and that the first entry in each cell of the matrix is the payoff to player 1 and the second entry is 2's payoff.

Notice first that, since we have assumed $y > x$ and $w > z$, each player obtains a higher payoff if he chooses D than if he chooses C, *no matter what strategy the other player chooses.* Thus, it is in each player's interest to choose D, no matter what he expects the other player to do. D is said to *dominate* C for each player.

However, notice now that, if each player chooses his dominant strategy, the outcome of the game is that each player obtains a payoff w, whereas there is another outcome (C, C), which yields a higher payoff to both players, since we have assumed $x > w$.

Let us say that an outcome (Q) is Pareto-optimal if there is no other outcome which is not less preferred than Q by any player and is strictly preferred to Q by at least one player. An outcome which is not Pareto-optimal is said to be Pareto-inferior. Thus, in the two-person Prisoners' Dilemma, the outcome (D, D) is Pareto-inferior.

If the players could communicate and make agreements, they would presumably both agree to choose strategy C. But this would not resolve the 'dilemma', since neither has an incentive to keep the agreement: whether or not he thinks the other player will keep his part of the agreement, it pays him to defect from the agreement and choose D.

C and D are the conventional labels for the two strategies in the Prisoners' Dilemma. They stand for Cooperate and Defect. I use them throughout this book, though they are not entirely appropriate: one player may 'Cooperate' (choose C) by himself, and he may 'Defect' (choose D) even though no agreement has been made from which to defect. In this book, Cooperation and Defection (with capital initials) will always refer to strategies in a Prisoners' Dilemma (or, in chapter 2, in some other game).

If communication between the players is impossible or prohibited, or if communication may take place but agreements are not binding on the players, then the game is said to be *non-cooperative*. The Prisoners' Dilemma is defined to be a non-cooperative game. If it were not, there would be no 'dilemma': the players would obtain (C, C) as the outcome, rather than the Pareto-inferior outcome (D, D). In the situations of interest in this book, communication is generally possible but the players are not constrained to keep any agreements that may be made. It is the possibility of Cooperation (to achieve the outcome (C, C)) in the *absence* of such constraint that will be of interest.

As a generalization of this two-person game, an N-person Prisoners' Dilemma can be defined as follows. Each of the N players has two strategies, C and D, available to him. For each player, D dominates C, that is, each player obtains a higher payoff if he chooses D than if he chooses C, no matter what strategies the other players choose. However, every player prefers the outcome $(C, C, \ldots, C)$ at which everybody Cooperates to the outcome $(D, D, \ldots, D)$ at which everybody Defects. Thus, as in the two-person game, every player has a dominant strategy but if every player uses his dominant strategy the outcome is Pareto-inferior.

Two-person and N-person Prisoners' Dilemmas can both be defined in the more general case when any finite number of strategies is available to each player. The generalization, which could be made in several ways, must at least have the characteristic that the predicted outcome is Pareto-inferior. In particular, it could again be stipulated that every player has a strategy which dominates each of the others, and if every player uses his dominant strategy the outcome is Pareto-inferior. I shall not elaborate on this here, as my discussion in this book will mainly be confined to the two-strategy games, though in chapter 2 I shall also consider games in which each individual can choose to contribute a continuously variable amount within some range.

Let us go back now to the 'tragedy of the commons'. In Garrett Hardin's account, each individual has in effect a dominant strategy: to add an animal to his herd on the common, to discharge his sewage untreated, to kill as many whales as possible and so on. Each of these corresponds to strategy *D*. The alternative, strategy *C*, is to refrain from doing these things. Hardin assumes, in effect, that *D* yields the highest payoff to each individual, no matter what strategies the other individuals choose (that is, no matter how many of them Cooperate); and he assumes that every individual prefers the mutual Cooperation outcome $(C, C, \ldots, C)$ to the mutual Defection outcome $(D, D, \ldots, D)$. In other words, individual preferences are assumed to be those of an N-person Prisoners' Dilemma.

Russell Hardin has argued explicitly that public goods interaction in sufficiently large groups – in fact 'the collective action problem' more generally – can be represented by the N-person Prisoners' Dilemma.[24] His analysis is as follows. Suppose that each of N individuals has the choice (and only the choice) between contributing and not contributing one unit of the cost of producing a non-excludable good (one unit of a *numeraire* private good) and that every unit contributed produces an amount of the public good with benefit r. Suppose that each individual's utility is nr/N if he does not contribute and $nr/N-1$ if he does, where n is the total number of units contributed. (Notice that this means that the public good exhibits some rivalness: each individual's utility declines with increasing N, which is the number of individuals who actually consume the good, since nobody is excluded.) Then, if *m other* individuals contribute, an individual's utility is mr/N if he does not contribute and $(m+1)r/N-1$ if he does. Thus, the first of these utilities exceeds the second if and only if $N > r$, which is independent of m. In other words, no matter how many other individuals contribute, it does not pay anyone to contribute as long as the size of the public (N) exceeds the ratio of benefits to costs (r). When $N > r$, the game is an N-person Prisoners' Dilemma (as defined above): each individual has a dominant strategy, and the outcome which results when everyone chooses his dominant strategy is for everyone less preferable than another outcome. But when $N < r$, the dominant strategy for every individual is to contribute and the resulting outcome is the only Pareto-optimal position.

This argument, if correct, would apply also to the public goods with which Hobbes was chiefly concerned, namely domestic peace and security and national defence. I shall indeed show (in chapter 6) that Hobbes assumed men's preferences in the absence of the state to be those of a Prisoners' Dilemma game. The remainder of Hobbes's theory can then be summarized, somewhat crudely, as follows: (a) in the absence of any coercion, it is in each individual's interest to choose strategy *D*; the outcome of the game is therefore mutual Defection; but every individual prefers the mutual Cooperation outcome; (b) the only way to ensure that the preferred outcome is obtained is to establish a government with sufficient power to ensure that it is in every man's interest to choose *C*.

This is the argument which I wish to criticize in this book. But there is one element of the argument which I shall not quarrel with, namely, the analysis of the Prisoners' Dilemma given above. If individual preferences in the provision of a public good are in fact those of a Prisoners' Dilemma, then it is quite correct to conclude that the players will not voluntarily Cooperate. To avoid any misunderstanding, I emphasize that the conclusion is correct no matter what the entries in the payoff matrix (which is assumed to be a Prisoners' Dilemma) actually represent, just as long as it is assumed that each player is concerned only to maximize his own payoff. Of course, the payoffs may not reflect *all* the incentives affecting the individuals in the situation in question. The conclusion still follows logically; but it is possible to argue that the payoff matrix is a poor description of the relevant real world situation and that in reality the players *do* Cooperate, because the omitted incentives are more important than those reflected in the payoff matrix.

In the next three chapters, the payoffs are assumed *not* to reflect, *inter alia*, (i) incentives due to external coercion, including that applied or threatened by the state or any other external agency or by other members of the group (apart from the tacit threats and offers which may be thought to be embedded in conditional Cooperation – about which more later); (ii) altruistic motivation; and (iii) any 'internal sanctions' like guilt, loss of self-respect and so on, which may result from failure to conform to a norm, live up to one's own ideals, perform one's duties, or whatever. In chapter 5 I shall begin with a matrix of payoffs which again do not reflect these three classes of incentives, but then I shall consider the effects of assuming that individuals are altruistic (that is, they take account of other players' payoffs as well as their own in choosing strategies).

The expression 'voluntary Cooperation', used occasionally throughout the book, refers to Cooperation chosen only on the basis of the matrix of payoffs (or utilities, where the individual is in some way altruistic); thus, voluntary Cooperation is Cooperation which, amongst other things, is *not* the result of external coercion, including that applied or threatened by the state.

The problem of collective action

I shall argue in the next chapter that, in many interesting problems of public goods provision, individual preferences at any point in time are *not* those of a Prisoners' Dilemma. Many other preference structures can arise. These include Chicken and Assurance games, whose two-person payoff matrices are shown below.

	C	*D*
C	3, 3	2, 4
D	4, 2	1, 1

Chicken

	C	*D*
C	4, 4	1, 2
D	2, 1	3, 3

Assurance

Surely, then, we should not equate 'the problem of collective action' with the Prisoners' Dilemma, as many writers have done – even though *some* of these alternative representations of public goods interaction (most notably the Assurance game) do not seem to present 'problems' in the sense which I think most people intend by use of the expression 'collective action problems'. What then do we mean by this expression?

Jon Elster gives a 'strong definition' of the collective action problem, which identifies it with the Prisoners' Dilemma, and a 'weak definition' which requires that (i) universal cooperation is preferred to universal non-cooperation by every individual (as in the Prisoners' Dilemma) and (ii) cooperation is 'individually unstable' and 'individually inaccessible'.[25] There is individual instability if each individual has an incentive to defect from universal cooperation, and there is individual inaccessibility if no individual has an incentive to move unilaterally from universal non-cooperation. But then he points out that there are cases in which cooperation is either individually unstable or individually inaccessible but not both – for example Chicken and Assurance games – but which nevertheless present collective action problems (though 'less serious' ones in the case of Assurance games).

The definition which I think gathers up all the cases that Elster and others are actually concerned with is that a collective action problem exists where rational individual action can lead to a strictly Pareto-inferior outcome, that is, an outcome which is strictly less preferred by every individual than at least one other outcome. The problem with this definition – an unavoidable problem, it seems to me, if one wants to give a general definition that covers *all* the cases one intuitively thinks of as collective action problems – is that it's not clear in some situations what rationality prescribes (even if we rule out, as I am assuming we should do here, notions of rationality not considered by game theorists). This is true of Chicken games. Any outcome of a Chicken game, including the Pareto-inferior mutual Defection outcome, can be rationalized. Hence, rational action *can* plausibly lead to a Pareto-inferior outcome, so that on my account it is a collective action problem.

Whether Assurance games are collective action problems again depends on what one takes rationality to prescribe. I shall take the view that, if a game has multiple equilibria (as the Assurance game does) but one of them is strictly preferred to all the others by everyone, then the Pareto-preferred one will be the outcome. On this view, rational action in an Assurance game does *not* lead to a Pareto-inferior outcome, so that this game is not a collective action problem.

Since preferences in some public goods interactions are those of an Assurance game, not all such interactions are collective action problems.

In the case of the (one-shot) Prisoners' Dilemma, rational action unequivocally leads to a Pareto-inferior outcome, so on my account all situations representable as Prisoners' Dilemmas are collective action problems. So are many other games (some of which will be encountered in the next chapter). Of course, not all of these games (including the Prisoners' Dilemma and Chicken games) correspond to public goods interactions.

Elster has said that politics is 'the study of ways of transcending the Prisoners' Dilemma'.[26] In the light of this discussion of 'the collective action problem' (and in anticipation of the discussion of alternatives to the Prisoners' Dilemma in the next chapter), I think we should be a little more expansive and say that politics is the study of ways of solving collective action problems.

Time and the lone exploiter

It's worth noting parenthetically that the degradation of a 'common' may *not* be the result of failure to solve a collective action problem. It may occur even where the common has only one user and he acts rationally.

The 'tragedy of the commons', on Garrett Hardin's account, arises because, at any point in time, each individual finds it in his interest to exploit the common (choose strategy D) no matter what the others do. The 'tragedy' does *not* arise, as some people have written, because each man reasons that '*since* the others are going to ruin the common anyway, I may as well exploit it too'. (In fact, if the others do *not* exploit the common, if they restrain themselves and choose strategy C, then each individual will find it even more profitable to exploit it than if they do.) It cannot be said, then, that the common would not be ruined if only *one* individual had access to it; that if a lake and all its lakeside factories were owned by one man, he would treat his wastes before discharging them into the lake; that if one man had an exclusive right to kill whales, he would see that they did not become extinct.

But surely, it may be said, the sole hunter of whales would not kill them all off, for his whole future livelihood, or at least all his future profits, depends on their survival. Unfortunately, this may not be the case.

Consider a common which one man has exclusive rights to exploit without restraint, and suppose now that at some point in time he is contemplating his whole future course of action with respect to this common. Let us suppose that he divides the future into equal time periods (months, years or whatever) and that in each time period he will receive a payoff. The sequence of payoffs he will receive depends on the course of action he chooses (for example, how many whales he kills in each period). Clearly, what he chooses to do will depend on the *present* value to him of future payoffs. At one extreme he may place no value whatever on any payoff except the one in the time period immediately before him. In this case, the prospect of zero payoffs from some point in

the future onwards (as a result of the extinction of the whales, for example) does not trouble him at all. He will act in each time period so as to maximize his payoff in the current time period, and the result may be the ruin of the common.

It is generally assumed that future payoffs are exponentially *discounted* to obtain their present values. In the case when future time is divided into discrete periods, this means that the present value of a payoff X_t to be made t time periods from the present is $X_t a^t$, where a is a number such that $0 < a < 1$ and $1-a$ is called the *discount rate*. The higher the discount rate, the lower the present value of future payoffs. If, for example, the individual's discount rate is 0.1 (that is, $a = 0.9$), then a payoff worth 100 units if received now would have a present value of 90 if it were to be received one period hence, 81 if it were to be received two periods hence and so on.

Intuitively, we should expect that if the discount rate is sufficiently high, then an exploiter who is seeking to maximize present value may eventually and quite 'rationally' ruin the common, even in the absence of other exploiters. The simple mathematics of this are set out by Colin Clark in his study of the exploitation of renewable resources (which, it should be remembered, include atmospheric, soil and water resources as well as such things as whales, fish and bison).[27] In the case when the resource of the common is a biological population, the discount rate which is sufficiently high to result in the extinction of the population will depend above all on the reproductive capacity of the population. (In Clark's model, this is *all* it depends on.)

The ruin of the common by a single individual, though it may be unfortunate, is not a 'tragedy' in Hardin's sense. (In the 'tragedy of the commons', the tragedy resides in the fact that 'rational' action on the part of each individual brings about a state of affairs which nobody wants.) Nor would it be a 'tragedy' if several individuals with similar preferences, including a shared high discount rate, ruined the common together, for this outcome would not be Pareto-inferior for them.

Solutions? Community, states, entrepreneurs, property rights and norms

There are, broadly speaking, two sorts of solution to collective action problems, which I will call 'spontaneous' or 'internal' solutions and 'external' solutions. *Internal* solutions neither involve nor presuppose changes in the 'game', that is, in the *possibilities* open to the individuals (which are in part determined by the 'transformation function', specifying how much of the public good can be produced with a given contribution), the individuals' preferences (or more generally *attitudes*), and their *beliefs* (including expectations). *External* solutions, on the other hand, work by changing the game, that is, changing people's possibilities, attitudes or beliefs. The changes do not necessarily originate outside the group of individuals who have the collective action problem. Since individual action is the product directly of the individual's possibilities, attitudes and beliefs, these two exhaust the possible sorts of solution.

It could be said that in the case where an internal 'solution' is forthcoming, there was no 'problem' there to solve. For example, if the 'problem' is correctly modelled as a dynamic game which, though it consists let us say of an iterated Prisoners' Dilemma, is not itself a Prisoners' Dilemma and as a consequence the outcome produced by rational egoists (without any external assistance or other interference) would be mutual cooperation throughout the game, then it could be said that preferences (*including intertemporal preferences*), etc., are such that there is no collective action *problem*. This would be a perfectly reasonable use of the word problem, but I shall not adopt it here. In fact, I shall take the view that the internal solution is the *basic* one, in two connected senses. It is, first, the only one which is complete in itself. All the external solutions presuppose the prior and/or concurrent solution of other problems, usually (always?) of collective action problems. Many of them, for example, involve the use of threats and offers of sanctions, and the creation and maintenance of the sanction system entail the prior or concurrent solution of collective action problems. (Why, for example, should the rational egoist pay his portion of the taxes that the state requires to maintain its police forces, etc., or why should the individual member of a community go to the trouble of punishing a free rider when he could be a free rider on the sanctioning efforts of others?) The internal solution is basic in a second sense: until we know whether a solution of this kind is possible and what form it will take, we cannot say what work, if any, remains to be done by other putative solutions. Thus, understanding the prospects for and obstacles in the way of an internal solution helps us to see what sorts of external solution are necessary and are likely to emerge in a given context.

External solutions can themselves be divided into two broad categories, which for short I will call centralized and decentralized; or, better, they can be arrayed along a continuum running from perfectly centralized to perfectly decentralized. Combinations of them are possible – normal, in fact. A solution is *decentralized* to the extent that the initiative for the changes in possibilities, attitudes or beliefs that constitute an external solution is dispersed amongst the members of the group; or, the greater the proportion of the group's members involved in solving the collective action problem (e.g. applying sanctions to free riders), the more decentralized the solution. Contrariwise, a solution is *centralized* to the extent that such involvement is concentrated in the hands of only a few members of the group.

Centralized solutions are typified, of course, by *the state*, while decentralized solutions characterize *community*. I have devoted another book to the ways in which a community can provide itself with public goods without the help of the state and will not reproduce the arguments here.[28] By a community I mean a group of people (i) who have beliefs and values in common, (ii) whose relations are direct and many-sided and (iii) who practise generalized as well as merely balanced reciprocity. The members of such a group of people, or all of its active adult members, can wield with great effectiveness a range of positive and negative sanctions, including the sanctions of approval and disapproval – the latter especially *via* gossip, ridicule and shaming. Decentralized solutions can sometimes be effective where there is little community, but the size of the group would still have to be relatively small (as it must be in a community).

External solutions are not necessarily restricted to the use of threats and offers of positive and negative sanctions. These, it is true, work not by altering an individual's preferences among outcomes (properly defined) but by altering his expectations about the actions to be taken by others (and hence the expected utility associated with alternative courses of action). But there are other ways in which an individual's expectations about others' behaviour can be altered and other ways in which he can be got to contribute to a public good, without the use of threats and offers or of force, whether centralized or decentralized. These include persuasion – providing information and arguments about the alternatives, about the consequences of adopting the various courses of action, about others' attitudes and beliefs and so on. Such methods are characteristic of the political entrepreneur, an external solution (relatively centralized, though usually closely combined with decentralized mechanisms) which I shall discuss shortly.

My main concern in this book is with the internal solution – with the possibility of spontaneous cooperation – as an alternative to the state. But before turning to this, I want to comment briefly, first, on the role of the political entrepreneur in the solution of collective action problems, and secondly, on the claims made by a number of writers that certain collective action problems can be solved by establishing private property rights and by norms.

Political entrepreneurs

In what sense do political entrepreneurs or leaders 'solve' collective action problems? In general, to solve or remove a collective action problem he or she must of course change individual preferences (or more generally attitudes), or change beliefs (including expectations) or inject resources (very probably knowledge, or new technology, like guns) into the group so as to make its members' efforts more productive.

Merely offering his services (working to obtain the public good) in exchange for support (subscriptions, food and shelter, or whatever) does not in itself constitute a distinctive solution to the problem. For, in the first place, the entrepreneur's services are themselves a public good, so that supporting him also gives rise to a collective action problem. This includes the case of the politician who in seeking electoral support offers his constituents legislative or other changes they favour. The collective action problem his potential supporters had in obtaining the public goods which such changes would have brought them is replaced by the collective action problem of getting him elected. And secondly, if the entrepreneur gains support by offering selective incentives, as well as by promising to work for the public good, then the solution is precisely the one proposed by Olson himself, in his 'by-product' theory.[29]

In many interesting cases the political entrepreneur may require little or no support from the members of the group whose collective action problem is at issue, because he is supported by (i.e., brings resources from) some external source. He might, for example, in his efforts to solve a *local* collective action problem, be supported by a pre-existing organization (the Communist Party, say, or the Catholic Church). This makes it easier to explain why the local problem is solved (for the members of the local group do not have to produce a 'surplus' to pay or

feed the entrepreneur), but it leaves unexplained (a) the production of the resources brought in by the political entrepreneur, which will usually entail that a prior collective action problem – for example the creation and maintenance of an organization – has been solved; and (b) how, even though the (local) group does not have to support the entrepreneur, it now manages to solve a collective action problem that it could not solve without him. If the only difference the entrepreneur makes is the addition of selective incentives to their benefits, then, once again, we do not have a distinctive solution.

But the political entrepreneur is not just 'an innovator with selective incentives',[30] or someone who simply concentrates or centralizes resources. What is perhaps more characteristic of political entrepreneurship is its role in changing beliefs – beliefs about the public good itself, about what others have done and are likely to do and about others' beliefs. Above all, we must remember that most collective action must involve some form of conditional cooperation, for at a minimum an individual would not cooperate if *nobody* else did. And as we shall see (in chapters 3 and 4) conditional cooperation is a very precarious business. It requires amongst other things that the conditional cooperators have information about others' behaviour. The required monitoring can be done by the political entrepreneur.

The entrepreneur can also try to persuade people that their contributions make a big enough difference, either directly or indirectly through their effect on others' behaviour. The second of these might be achieved by persuading people that others' efforts are contingent on theirs.

An organization whose aim is to provide public goods for a very large group might be able to expand its membership and achieve its aims by having its cadres work to solve, through any or all of these entrepreneurial methods, smaller-scale collective action problems for much smaller subgroups. A nationwide movement, for example, may be built upon the success of its cadres in solving local collective action problems and bringing tangible benefits quickly. Samuel Popkin has given an excellent account of activities of this sort in Vietnam, showing how four politico-religious movements (the Catholic Church, the Cao Dai, the Hoa Hao and the Communist Party) won support by having their cadres help the villages, both by providing selective incentives and by facilitating cooperation in the provision of public goods.[31] These private and public goods – with varying degrees of indivisibility and excludability – included the provision of educational opportunities; the creation of insurance and welfare systems; agricultural improvements; the establishment of stock-farm cooperatives; improvements in water storage and irrigation facilities; the creation of local courts to arbitrate disputes; and protection against French courts, marauding notables and local landlords.

Property rights

Many economists, and nearly all those of the 'property rights' school, believe that the solution to free rider problems in public goods provision, and in particular those which would lead to the over-exploitation of a 'common property resource', lies in the establishment of private property rights. Without such rights, the argument goes, every individual has an incentive to intensify his use of the resource because (as we saw in discussing Garrett Hardin's 'tragedy of the commons') although, with each increment in use, every unit of his (and everybody else's) input becomes slightly less productive, this is up to a point outweighed by the marginal return from the increased input. Intensifying use of the resource is continued up to the point where all the 'rent' (income or other return) from the resource has been dissipated. Likewise, the benefits arising from any improvement or renewal or other investment he might make in the resource would be shared by all the users while the costs would be borne by the individual alone. There will therefore be overuse and underinvestment. With the establishment of private property rights, however, the external effects of each individual's actions are 'internalized': *all* the costs of an increase in use of the resource are borne by the individual, as are all the benefits of investing in its conservation or improvement.

The argument that the 'tragedy of the commons' is the fate of common property resources, and that overuse or underinvestment will be avoided only if common property rights are displaced by private property rights, seems to be positively mocked by the facts. The commons of the European open field system, far from being tragically degraded, were generally maintained in good health during the whole of their lifetimes of many hundreds of years. There is a detailed study of a Swiss alpine village (not, of course, operating an open field system) whose members have for more than five hundred years possessed and used in common

various resources, including mountain-side pastures, side by side with privately owned land and other resources and during all this time the productivity of the common land has been maintained and much effort has been invested in its improvement.[32] Contrast with this the treatment, especially in recent decades, of much privately owned land by its very owners: the destruction of vast tracts of rain forest for the sake of a few profitable years of ranching; or the set of practices which together are causing the loss of topsoil from cultivated land through wind and water erosion on such a scale that, according to a recent report, there will be a third less topsoil per person by the end of the century.[33] In parts of Africa, and elsewhere in the world, overexploitation of grazing lands has been caused not by common property arrangements *per se* but by their destruction or disruption.[34] There are, as we saw earlier, perfectly good reasons why the rational private owner or user of a resource might knowingly destroy it; in particular, he might place a very low value on benefits to be derived from the resource in the distant as opposed to the immediate future.

Where do the property rights economists go wrong?[35] In the first place, many of them do not distinguish common property in a resource from *open access* to it. 'Communal rights', say Alchian and Demsetz, '. . . means that the use of a scarce resource is determined on a first-come, first-serve basis and persists for as long as a person continues to use the resource'.[36] This is wrong, or at least an abuse of language. If there is open access, then nobody is excluded from using the resource and there is no regulation of the activities of those who do use it. But if there is common ownership or collective control of the resource, then the members of the collectivity, whatever it is, can regulate its use. This is what happened in the European open field system, where the villagers rigorously excluded outsiders from use of the various commons they owned or possessed collectively, and carefully regulated insiders' use, typically by allotting to individuals 'stints' in proportion to their (privately owned) arable holdings and punishing people for infringements. The alpine community described by Netting similarly practised strict external and internal regulation of its commons. So too have countless 'primitive' collectivities and peasant villages all over the world.

It is to resources with open access, not to 'common property resources', that the property rights economists' argument about over-exploitation and underinvestment applies. It is not a matter of establishing the right sort of property rights, of moving from collective to private property rights. It is rather a matter (at this stage of the argument at least) of establishing property rights where there were none; for property entails exclusion, so that where there is open access to a resource, there is no property in it.[37]

The property rights economists tend to see only two or three possibilities: open access and private property, to which is sometimes added state ownership. But almost any group of individuals can own or possess property collectively. Historical and contemporary examples are: a family; a wider kin group, such as a matrilineage; all those in a village who also possess land privately; a band; an ethnic group. Where the property rights economists do notice common property rights, they then argue that the costs of negotiating agreements regulating use and, if agreements are forthcoming, the costs of policing them, will be very great, and in this respect, common property rights compare unfavourably with private property rights.[38] But there is no necessary reason why transaction costs of all kinds should in total be greater in the case of common property rights than in the case of private property rights – and in the case of the open field system it was in fact the other way round, essentially because of economies of scale in pastoral production.[39]

Finally, the property rights economists, having generally failed to notice common property (as opposed to open access) and to study how individual rights in it are guaranteed, tend to assume that property rights must be enforced by the state.[40] But there can also be decentralized enforcement or maintenance of property rights – both private and common. (The sense of 'decentralized' intended here is the same as that used in the general remarks made earlier on the solution of collective action problems.) If a collectivity itself is to enforce its members' private property rights or their rights to use the common property, then it must of course be able to wield effective sanctions – unless the property rights are respected as a result of 'spontaneous' conditional cooperation. If the collectivity is a community, then, as we have seen, conditions are conducive to conditional cooperation, and if this fails the community's members have at their disposal a range of effective sanctions. The joint owners of the commons in European open field villages, for example, were communities in the required sense.

Enough has now been said, I think, to show that, insofar as the

solution of collective action problems is concerned, nothing new is added by the introduction of property rights *per se*. An individual has property in something only if others forbear from using it, and the forbearance is the result of the threat or offer of *sanctions*, centralized or decentralized (or of conditional cooperation – unless this be reckoned also to involve threats and offers). It is the threats and offers of sanctions (and/or conditional cooperation) that is solving the collective action problem, if it is solved at all. Furthermore, as I remarked in an earlier section, the use of some of these sanctions presupposes the solution to prior collective action problems (for example, the formation and maintenance of a state!).

Norms

There is, finally the suggestion that norms solve collective action problems. I will comment on this very briefly, for my reaction to it is similar to my view of the suggestion that the introduction of private property rights solves collective action problems, and both follow from the general remarks about solutions to these problems made in an earlier section (though I shall not argue, as some have done, that property rights *are* norms). The view that norms solve collective action problems – or more precisely that they solve, amongst other things, the problems inherent in 'generalized PD-structured situations' and coordination problems – has been expounded by Edna Ullman-Margalit.[41] I shall take it that a norm is generally conformed to and is such that nonconformity, when observed, is generally punished. It is unclear whether this is what Ullman-Margalit means by a norm, but in any case it is fairly clear from her discussion of 'PD norms' that it is only 'a norm, *backed by sanctions*' or 'a norm . . . *supported by sufficiently severe sanctions*' that is capable of solving Prisoners' Dilemma problems.[42] So norms alone – mere prescriptions for action that people generally conform to – do *not* solve these problems.

If a norm is generally observed simply because it pays the individual to do so (in the absence of sanctions), then there is no (collective action or other) 'problem' to be solved in the first place. This would be the case if the norm had been 'internalized'. I take this expression to indicate that conformity to the norm does not require the application of external sanctions, inducements or any other considerations; as a result of the norm being internalized, the individual *prefers* to conform (without the threat of punishment) or at least has some sort of motivational disposition to do so. But then, as I say, we would not say that there was a Prisoners' Dilemma or collective action 'problem' to be solved: the individual preferences would not be those of a Prisoners' Dilemma or would not be such as to lead to a collective action problem. Of course, we might nevertheless wish to explain how the norm came to be internalized or how people came to have such preferences.

If, on the other hand, a norm is generally observed because non-conformity, when noticed, is generally punished, then it is the sanctions that are doing the real work of solving the Prisoners' Dilemma or collective action problem. The sanction system can of course be centralized or decentralized, in the way discussed in an earlier section. And again, it remains to be explained how the system of sanctions itself came into being and is maintained. To this problem, the general point made earlier about sanction systems applies: the maintenance of a system of sanctions itself constitutes or presupposes the solution of another collective action problem. Punishing someone who does not conform to a norm – punishing someone for being a free rider on the efforts of others to provide a public good, for example – is itself a public good for the group in question, and everyone would prefer others to do this unpleasant job. Thus, the 'solution' of collective action problems by norms presupposes the prior or concurrent solution of another collective action problem. And as my earlier remarks make clear, this would still be the case if the sanctions were wielded by the state or by a political entrepreneur.

Plan of the rest of the book

My purpose in this book is to examine the possibility of voluntary cooperation in the provision of public goods and in the solution of other collective action problems, and in doing so – and in other ways – to raise questions about what I take to be the most persuasive justification of the state. The detailed study of voluntary cooperation which follows (chapters 2, 3 and 4) can be read – and evaluated – independently of the critique of the liberal theory of the state. Both as a study of cooperation and as a study of the state and its alternatives, it is obviously far from complete; another part of the story is tackled in my *Community, Anarchy and Liberty*, which is complementary to this book.

As a critique of the liberal justification of the state, the argument will be in three stages. First, I argue in chapter 2 that in public goods interactions the individual preferences at any point in time are not necessarily those of a Prisoners' Dilemma game. This is true, I shall argue, of both two-person and N-person games and of cases where strategy sets are continuous as well as those where individuals have only two strategies available to them. It will emerge that important classes of public goods provision problems are better represented by Assurance and especially Chicken games, and in the continuous case by hybrids of these two. In all these games, arguably, if the game is played only once, *some* cooperation is more likely to be forthcoming than in cases for which the Prisoners' Dilemma is the appropriate model.

In the next two chapters (3 and 4), however, I shall assume the worst: that preferences at any point in time are those of a Prisoners' Dilemma game. But I then go on to show that if *time* is introduced and the problem is treated more dynamically, under certain circumstances voluntary Cooperation is rational for each player, even assuming that he seeks to maximize only his own payoff.

My argument here will be cased in terms of the Prisoners' Dilemma *supergame*. This is the game consisting of an indefinite number of iterations of one of the Prisoners' Dilemma games (two-person and N-person) which were defined earlier. In each *constituent game* (as the repeated game is now called), players choose strategies simultaneously, as before, but they know the strategies chosen by all other players in previous games. Each player discounts future payoffs; his discount rate does not change with time, but discount rates may differ between players. The constituent game is assumed not to change with time. (It would be desirable to relax this last assumption in a more general treatment, and permit the payoff matrix to change with time. See the final section of chapter 4 below.)

The really important difference between the one-shot game and the supergame is that players' strategies can be made interdependent in the latter but not, of course, in the former, since players must choose strategies simultaneously or in ignorance of each other's choices. In the supergame, a player can, for example, decide to Cooperate in each constituent game *if and only if* the other player(s) Cooperated in the previous constituent game. It is on this possibility, the possibility of using *conditional* strategies, that the voluntary Cooperation of all the players turns.

Finally, in chapter 7, I shall raise doubts about the way in which this justification of the state is approached. It is an essential and fundamental feature of the theory I am criticizing that it takes individual preferences as given and fixed. In particular, it is assumed that the state itself has no effect on these preferences. This rules out *ab initio* the possibility, amongst many others, that the state may exacerbate an already existing collective action problem or create such a problem where none existed before: that the state may affect, in other words, the very conditions which are supposed to make it necessary. If preferences may change, especially as a result of the activities of the state itself, it is not at all clear what is *meant* by the desirability of the state.

Criticisms of this sort can of course be levelled against any theory which is founded on assumptions about fixed individual preferences (as most of economic theory and some polotical theory is); but they are especially important, it seems to me, when the theory purports to justify an institution (like the state) and when the theory is to apply to a very long period of time (as a theory used to justify the state or to explain its origin must do).

I have said that the arguments which are the object of my criticisms in this book have been set out most explicitly by Thomas Hobbes. I shall therefore give (in chapter 6) an exposition of his political theory. My chief reason for devoting to this exposition a rather long chapter later in the book, rather than a short summary at the start of the book where it would otherwise belong, and for making what would otherwise be an unpardonable addition to the considerable critical literature on Hobbes, is that I think it is illuminating to look at these theories in terms of some of the ideas presented in the earlier chapters on the Prisoners' Dilemma and its supergame. I have asserted rather baldly in this informal Introduction that Hobbes's theory is about non-Cooperation in Prisoners' Dilemma games (other writers have made similar assertions, equating Hobbes's theory with, for example, Hardin's analysis of the 'tragedy of the commons'); but the story is more complicated and more interesting than this and deserves a fuller account.

I shall also consider, more briefly, David Hume's political theory. For although it is very similar to Hobbes's theory (despite Hume's objections to what he took to be a fundamental element of Hobbes's theory, the idea of the social contract) and although it is generally less rigorous than Hobbes's version (in *Leviathan*), it does partly supply a deficiency in Hobbes's treatment, namely that it is too static. Hobbes in effect treats only a one-shot Prisoners' Dilemma game, whereas Hume's treatment is more dynamic, with the discounting of future benefits playing an important role. Also, in Hume, but not in Hobbes, there is explicit recognition of the effects of size, a partial anticipation of Olson's 'logic of collective action'.

Some of the ideas I am interested in here appeared much earlier than *Leviathan* (above all in the *Book of Lord Shang* and the works of Han Fei Tzu which were written in China in the fourth and third centuries BC), but it was Hobbes and Hume who gave the first full, explicit statements of the argument. And in later political theorists the argument is not always explicit, does not stand out boldly and is less precise and less coherent.

In *Leviathan*, Hobbes seems to assume that each man seeks to maximize not merely his own payoff, but also his 'eminence', the difference between his own and other people's payoffs. Hume, on the other hand, assumes that most people are chiefly concerned with their own payoffs but are also possessed of a limited amount of 'benevolence'. In both cases, individuals take *some* account of other individuals' payoffs; I call this 'altruism'. The effects of various sorts of altruism on the outcomes of Prisoners' Dilemma games are treated briefly in chapter 5. Some of the material in that chapter will be of use in the discussion of Hobbes and Hume and also in the final chapter.

2. The Prisoners' Dilemma, Chicken and other games in the provision of public goods[1]

It has often been said – and indeed is still being said – that 'the problem of collective action and the Prisoner's Dilemma are essentially the same'[2] (at least where the group is large or where it is not privileged) *and* that the Prisoners' Dilemma game is the appropriate model of public goods provision. Neither of these is the case. The argument against the first claim – which has been made by a number of writers, most explicitly perhaps by Russell Hardin[3] – was begun in the last chapter. Against the second claim I argue in this chapter that the Prisoners' Dilemma is *not* the only applicable game in the study of public goods provision. Since many (though not all) important collective action problems arise in connection with the provision of public goods, this chapter, in attacking the second claim, will also attack the first.

More specifically, I shall argue that in public goods interaction the individuals' preferences *at any point in time* are not necessarily those of a Prisoners' Dilemma. I shall argue this, first, in the case where the individuals choose between just two strategies, Cooperate (or contribute to the provision of the public good) and Defect (not contribute), and then in the case where each individual can choose to contribute a *continuously* variable amount within some range (or choose from a large number of discrete amounts which may be approximated by a continuous variable). We shall see in particular that important classes of public goods provision problems are better represented by the game of Chicken, both in the two-strategy, two-person case and in the two-strategy, *N*-person case to which Chicken can be generalized, and that structures of preferences can also be 'Chicken-like' in the case when the strategy sets are continuous.

I emphasize that this chapter does not begin to consider the *dynamics* of choice in public goods interaction; it is concerned only with individual

preferences at one point in time and with choices in one-shot games.[4] Genuinely dynamical considerations enter into the analysis in the next chapter, which considers *repeated* plays of the Prisoners' Dilemma, or 'supergames'. These supergames are themselves typically *not* Prisoners' Dilemmas. So this chapter and the next two will establish (amongst other things) that preferences in public goods interaction at a point in time are often not those of a Prisoners' Dilemma and that, even if they are, the 'dynamic' or intertemporal preferences of the resulting supergame are usually not.

Alternatives to the Prisoners' Dilemma

If a 2×2 game is to be a Prisoners' Dilemma, then amongst other things each player must (a) prefer non-Cooperation if the other player does *not* Cooperate, and (b) prefer non-Cooperation if the other player *does* Cooperate. In other words: (a′) neither individual finds it profitable to provide any of the public good by himself; and (b′) the value to a player of the amount of the public good provided by the other player alone (i.e., the value of being a free rider) exceeds the value to him of the total amount of the public good provided by joint Cooperation *less* his costs of Cooperation. Of course a player could not even form these preferences if it were not *possible* for each player to provide some of the public good *alone*. For many important public goods, I shall argue, either or both of the conditions (a′) and (b′) fail, and sometimes even this precondition for forming the preferences in question may fail.

If (a′) fails for at least one of the players – if one of them has an incentive to provide some amount of the public good even if he alone has to pay the full costs – then we have what Olson calls a 'privileged' group. In this case there is, according to Olson, a 'presumption' that the public good will be provided by the players. If only one of the players is willing to act unilaterally in this way, this presumption is reasonable. But if both

	C	*D*
C	3, 3	1, 4
D	4, 1	2, 2

Figure 1 The 2×2 Prisoners' Dilemma

are so willing, so that the group is 'doubly privileged', then there should be no such presumption, unless each player is willing to contribute *regardless* of what the other player does, that is, if C is a dominant strategy for each player. If, however, each player is willing to provide some of the public good unilaterally *but not if the other player will provide it* – that is, if condition (a′) fails but all the other assumptions of the Prisoners' Dilemma game are retained – then we have a game of *Chicken*, and in a game of Chicken it is not at all obvious what the outcome will be, as we shall see.

	C	*D*
C	3, 3	2, 4
D	4, 2	1, 1

Figure 2 The 2 × 2 Chicken Game

This structure of preferences is more appropriate than the Prisoners' Dilemma game as a model of certain widespread reciprocity practices involving the production of public goods and, especially in its N-person generalization which we shall look at shortly, of a variety of situations involving ecological or environmental public goods. Consider, for example, two neighbouring cultivators whose crops depend upon proper maintenance of dykes and ditches for flood control or irrigation. There is a minimum amount of work which must be done; *either individual alone can do it all*, but each prefers the other to do all the work. The consequences of *nobody* doing the work are so disastrous that either of them would do the work if the other did not. The structure of preferences here is that of the game of Chicken.

Not all reciprocity or mutual aid practices resemble games of Chicken. If the product of the reciprocal assistance is not itself a public good, the game is more likely to be a Prisoners' Dilemma. Consider, for example, our two neighbouring cultivators, each of whom can choose to give or withhold assistance to the other at crucial times, such as when they need to get a harvest in quickly. With help, each gets enough done to enjoy a satisfactory winter; without help, a miserable winter of near-starvation ensues. Then (*if* we isolate this game from any wider or continuing relations between the two individuals) each player would prefer to have the other help him without having to return the favour (i.e., to be a

unilateral Defector) rather than mutual assistance (since helping the other is costly); and each would prefer mutual Defection to being a unilateral Cooperator, since in either case he would have no help (in getting his harvest in, etc.). Mutual Cooperation is nevertheless preferred by both players to mutual Defection. This game is therefore once again a Prisoners' Dilemma. It is, in fact, just an instance of *exchange*, in which each party has a choice between yielding up his good or service (C) and holding on to it (D). The asymmetric outcomes, where one player yields and the other does not, would normally be said to involve stealing. In anarchy, games of exchange/stealing are generally Prisoners' Dilemmas.[5]

For a second example of public goods interaction resembling a Chicken game, consider the case of two large factories which discharge effluent into a small lake. Each producer can choose between polluting (D) and refraining from polluting (C). The lake can absorb waste from one factory and still remain usable, but the wastes from both factories carry it over a critical threshold. The resulting ecological catastrophe is so bad that each producer, though he finds a free ride on the restraint of the other producer preferable to mutual Cooperation, would prefer to refrain unilaterally if the other producer pollutes (the cost of refraining deducted from the benefits derived from this unilateral restraint being less than the (dis)utility of the catastrophe).

We have here a case of a public good which is not provided in smoothly increasing amounts as the level of contributions increases. Ecological systems such as lakes, rivers, the atmosphere, fisheries and so on can normally be exploited up to some critical level while largely maintaining their integrity and retaining much of their use value. If exploitation rates go beyond that critical level, use value falls catastrophically. With fisheries, for example, once the population has fallen below that necessary to maintain a viable breeding stock the species will rapidly cease to be commercially exploitable. Although the use value of the 'common' may decline somewhat as rates of exploitation approach the critical level, it falls catastrophically beyond that level.

A similar sort of discontinuity is found with many public goods of the 'public works' variety, such as road and rail links and bridges, which cannot be usefully provided in *any* amounts but only in more or less massive 'lumps' or *tranches*. In some cases *no* amount of the public good can be provided until total contributions exceed some threshold. If, in the 2 × 2 game, a single individual's contribution is insufficient to provide any of the public good, or provides only a very little of it, then each player will prefer D if the other player chooses D, but may prefer to contribute if the other contributes too. In this case, we have a variant of a third type of game, the game of *Assurance*.

	C	D
C	4, 4	1, 2
D	2, 1	3, 3

Figure 3 The 2 × 2 Assurance Game

Consider again a reciprocity practice which produces a public good: the maintenance of dykes and ditches for irrigation or flood control by two neighbouring cultivators. We saw earlier that if one of them *alone* could do all the necessary work (though of course preferring that the other did it all) and *would* do if the other did not (to avoid disaster), the resulting game is one of Chicken. Now suppose that neither individual can alone produce any of the public good: if the benefit of the public good to each of them is 4 and the cost of contributing is 2, we have the First Variant of the Assurance game shown in Figure 4. If one individual alone can produce *some* of the public good (with a benefit to each of 1, say) but not enough to justify his costs (2, again), then we get the Second Variant of the Assurance game. For another example of this case, consider two members of a community sharing a vegetable patch: one individual's weeding does not keep pace with the growth of weeds, though it enables *some* crop to be grown; if both weed, the crop will be good.

We see, then, that the games of Chicken and Assurance, as well as the

	C	D
C	2, 2	−2, 0
D	0, −2	0, 0

First Variant

	C	D
C	2, 2	−1, 1
D	1, −1	0, 0

Second Variant

Figure 4 Two variants of the Assurance Game

Prisoners' Dilemma, can be relevant to the problem of collective action to provide public goods. This conclusion will be reinforced when we come to consider the N-person generalizations of these games and allow for the individual's choice of contributions to vary continuously.

When individual preferences are those of an Assurance game, there is unlikely to be a problem of collective action to provide the public good, as there is when the game is a PD. The 2 × 2 Assurance game, in its standard form or in either of the variants, has two equilibria (C, C) and (D, D), but since both players prefer (C, C) to (D, D), neither will expect the latter to be the outcome, so the unique Pareto-optimal outcome (C, C) will result.

But there is an interesting collective action problem in a Chicken game. The important feature of this game is that there are two equilibria and in each of these one player Cooperates while the other has a 'free ride' on the public good provided out of his contribution, so that it will pay each player to attempt to be the first to bind himself irrevocably to non-Cooperation, if this is feasible. *This pre-commitment strategy 'forces' the other player into Cooperation.* However, where each player is able to bind himself in this way both may realize the dangers of simultaneous binding and may forgo this for the fully Cooperative outcome. This is, unfortunately, unstable (at least in the single play game) so that one can expect any Cooperation to be fragile. I shall discuss the possibility of Cooperation in Chicken games at length below.

	C	D
C	3, 3	1, 4
D	4, 2	2, 1

Figure 5 PD for Row, Chicken for Column

If Chicken and Assurance as well as Prisoners' Dilemma games can characterize public goods interaction, then there is no reason why *hybrids* of these games should not also arise. Consider for example the game, whose payoff matrix is shown in Figure 5, in which the Row-chooser's preferences are those of a Prisoners' Dilemma while the Column-chooser's preferences are those of a Chicken game. Preferences might take this form because Column (i) values the public good much more highly than Row does, or can provide some amount of it at lower cost or is better able to contribute to it than Row, or again because he suffers much more than Row if none of the public good is provided at all and hence is willing to provide some of the public good if Row provides none, but (ii) does not value the public good so highly, or does not value large amounts of it sufficiently highly that he would be prepared to contribute *more* of it if Row provided some. The outcome of this game, unlike that of the pure Chicken game, is not at all problematic. Row will of course choose his dominant strategy *D* and this will make it rational for Column to choose *C*, so that the outcome is (*D*, *C*). This is the only equilibrium and it is the only Pareto-optimal strategy pair.

An *N*-person game of Chicken

Few interesting games in the real world (outside of international relations) have only two players. So the *N*-person generalizations of the games considered in the last section are of greater interest than the two-person versions. An *N*-person generalization of the Prisoners' Dilemma was discussed briefly in chapter 1. If this game is played only once, there is no more to be said about it: universal Defection will be the outcome. When the game is repeated, it's another story altogether, as we will see in chapter 4 (where we will also see that the *N*-person Prisoners' Dilemma supergame can be a Chicken game). The natural way to generalize the Assurance game is to stipulate that (i) universal Cooperation is preferred by each player to universal Defection, and (ii) an individual will prefer *C* to *D* if at least a certain number of other players Cooperate but otherwise will prefer *D* to *C*, so that the only equilibria are universal Cooperation and universal Defection, and any 'intermediate' strategy vector (in which some players Cooperate and some Defect) will not be an equilibrium because each player will want to change strategy either to *C* or to *D*. Again, the analysis of this game is unproblematic: universal Cooperation will be the outcome, since of the two equilibria it is preferred by every player to the other.

The most interesting of these (one-shot) games is Chicken. Its generalization to any (finite) number of players is less straightforward. It seems to me that the central feature of the 2×2 game which should be retained in any such generalization is the existence of an incentive for each player to attempt to bind himself irrevocably to non-Cooperation

Table 1

	If both the others Cooperate	*If one Cooperates, the other Defects*	*If both the others Defect*
G1: I prefer	*D* to *C*	*C* to *D*	*C* to *D*
G2: I prefer	*D* to *C*	*D* to *C*	*C* to *D*
G3: I prefer	*D* to *C*	*C* to *D*	*D* to *C*
PD: I prefer	*D* to *C*	*D* to *C*	*D* to *C*

(or at least to convince the others he is certain not to Cooperate), an incentive deriving from his expectation that such a commitment will compel some or all of the other players to choose Cooperation (on which he is then able to free-ride). So we define an *N*-person Chicken to be any game having this property, with the qualification that the pre-commitment incentive exists before the *costs* of commitment are taken into account. (Pre-commitment is sometimes costly and may be so costly as to remove the incentive.) It is of course assumed that each player prefers universal Cooperation to universal non-Cooperation and that each player's most preferred outcome is that he choose *D* while all others choose *C* (this is his most profitable free ride). As it stands the definition does not fully determine the permissible structures of preference. A three-person case illustrates this. We know that each player prefers *D* to *C* if both of the other players choose *C*. There are then four possible preference structures. One of these is a PD (the only one in which *D* dominates *C*) and the remaining three are labelled G1, G2 and G3. These four games are shown in table 1, which gives the preferences between *C* and *D* of any one of the players (called 'I') in each of the three possible contingencies (it being assumed that the game is symmetric, so that the preference structures shown are invariant under any permutation of the players). Each player is assumed also to prefer (*C*, *C*, *C*) to (*D*, *D*, *D*).

Now in the 2×2 Chicken game, each player prefers to Defect if the other Cooperates but prefers to Cooperate if the other Defects. A natural *N*-person generalization of this is to stipulate that each player prefers to Defect if 'enough' others Cooperate, and to Cooperate if 'too many' others Defect. This requirement is met in the 3-person game by G1 and G2 above; and more generally, for any number of players, the preferences of any player must switch direction from '*D* to *C*' to '*C* to *D*' only once as the number of players choosing *D* increases. (This corresponds to a rightward movement in a row of table 1 above.) Now in the three games shown above, the last two columns can also be viewed as the game between the first two players when the third (a Defecting column-player in table 1) has already committed himself to non-Cooperation. These two columns can now be headed by '*C*' and '*D*'. Let us assume that in all these 2×2 subgames (C, C) is preferred by each player to (D, D). In G1, then, the new row-player will choose *C* (since he prefers *C* to *D* whether the column-player chooses *C* or *D*). So will the new column-player, who has identical preferences. Thus, if one player pre-commits himself to *D*, the others are certain to choose Cooperation. The incentive for each player to pre-commit is therefore strong.

In G2, the 2×2 subgame remaining when one player has pre-committed himself to *D* is a Chicken game. Since, as we shall see, there is no obviously, unequivocally rational strategy to pursue in a Chicken game, a row-player who commits himself to *D* cannot be certain that this will compel the remaining players to Cooperate. But since there is a reasonable likelihood that they will, so that there is *some* positive incentive to pre-commit oneself to *D*, I shall allow that G2 is also a case of Chicken.

In G3 the 2×2 subgame remaining when one player has pre-committed himself to *D* is a game of Assurance, so the player contemplating pre-commitment can be virtually certain that this will compel mutual Cooperation amongst the others. In fact, for each player in G3 *D* is better than *C* if no others Cooperate or if two others Cooperate, but if one other Cooperates, *C* is the best strategy. So each player is in two possible Cooperative coalitions and will be tempted to try to 'force' the other two into Cooperation by pre-committing himself to non-Cooperation. According to our central criterion, then, G3 qualifies as an *N*-person Chicken game. But notice that G3 does not have the feature, mentioned above and possessed by G1 and G2, that each player prefers to Defect if 'enough' others Cooperate and to Cooperate if 'too many' others Defect. Games possessing this feature also have the property that each player has an incentive to pre-commit himself to non-Cooperation, but the converse is not true, as G3 shows. It is the existence of this pre-commitment incentive (if the cost of pre-commitment is ignored) which I believe to be the distinguishing feature of the 2×2 game of Chicken; accordingly I prefer the broader definition of the *N*-person game which admits any game having this feature.

It is clear, then, that in the *N*-person Chicken, as in the *N*-person Prisoners' Dilemma, rational individual action can lead to the unintended consequence of a Pareto-inferior outcome. For in the rush to be among the first to make a commitment to non-Cooperation (and thereby secure a free ride on the Cooperation of others), the number so binding themselves may exceed the maximum number of players able to commit themselves without inducing non-provision of the public good. Nevertheless, the prospects for Cooperation are a little more promising in Chicken games than they are in the Prisoners' Dilemma. I return to this later. Before doing so, let us again consider, in the light of this account of the *N*-person game, a few examples showing the relevance of the Chicken game to practical problems of public goods provision.

Mutual aid, fisheries, and voting in committees

All three variants of the three-person Chicken game, G1, G2 and G3, can characterize reciprocity and environmental situations of the sort already mentioned. Consider again the example of the irrigation and flood control system. Suppose now that it is a public good for three cultivators, any one of whom is able profitably to do the necessary work, the additional benefit (from the increased provision of the public good) to any other player who assists the first being less than the costs of such a contribution. Again, each prefers the others to do the work, but the consequences of nobody doing the work are so disastrous that each would do the work if nobody else did it. The preferences here are those of the Chicken game G2. If the job can be done profitably by one player alone, but can be done so much better by two players that it pays a player to contribute if another player is already doing so, then the preferences are those of G1. If the job cannot be done by any one of the players alone but can be done by two of them with profit to each, then the preferences are those of G3.

For an environmental example, consider a fishery, which can profitably be exploited up to some critical level beyond which there is catastrophic collapse. There are no plausible further assumptions in this case which would yield the game G3. But suppose that the fishery can tolerate one or two users, while three would surpass the critical level. Fishing being costly, if two are already fishing the third would prefer to refrain. Then (with other appropriate assumptions) the game is G2. Each player should want to be one of the pair which can 'force' the third into refraining from fishing. If at least two players must refrain from fishing to prevent collapse, and the much reduced catch which a player would get if either one or two others were fishing yields less benefit than the fishing would cost, then the game is G1. Each player should want to be the sole player who can enjoy a free ride on the remaining two by pre-committing himself to fishing and 'forcing' the others (who are then in an Assurance game) into restraint.

This is of course a highly stylized model of a fishery, and if we were to examine a real world 'fishery' we would find a much messier picture. In the case of whaling, for example, I think it can be plausibly argued that, although the 'game' once resembled a Prisoners' Dilemma, for the period from about 1947, when the International Whaling Commission was formed, Chicken would be a better approximation.[6] In the recent period, which saw the elimination of all the major whaling nations except Japan and the USSR (as well as the commercial extinction of the Blue Whale and other commercially important species), the behaviour of Japan and the USSR can be interpreted as attempts to demonstrate their commitment to non-Cooperation with a view to forcing other whaling nations to withdraw from the market, that is, to force them into Cooperation.

My final illustration of a public goods problem to which the game of Chicken is appropriate is less speculative. It concerns the rationality of the act of voting, which involves a perfectly lumpy public good.

Suppose that two options, *A* and *B*, come up before a committee operating under simple majority rule. Attendance and voting is optional. There is a group of players who both prefer *A* and know that they collectively constitute a majority of the players. For this group *obtaining A* is a pure *lumpy* public good (even if *A* itself *is not* a public good). Assume for simplicity that all players outside the group (who prefer *B*) turn up. So long as just enough of the *A*-supporters to form a bare majority turn up, the public good is provided; if less than this number turn up, none of the good is provided. There is no advantage in additional members over and above the bare majority turning up. So long as we can assume that the advantages of *A* over *B* are greater than the cost of voting for members of the majority group, the situation is modelled rather well by Chicken. Each member of the group will attempt to be among the first to find convincing reasons for being unable to attend the committee. There are three possible outcomes: either a group

just sufficient to get *A* through is 'forced' into attending; or if the group members are risk averse and the issue is vital they might all turn up, realizing the danger that *A* will not be passed; or insufficient of them attend to get *A* through and the public good is lost. In the first and second situations voting is perfectly rational for those who do attend (on expected payoff grounds in the second case).

For obvious reasons this argument makes more sense where numbers are small (as in committees) than where they are very large (as in constituencies).

Pre-commitment as a risky decision and the prospects for cooperation in Chicken games

If for whatever reasons it happens that the players in a game of Chicken are not all identically placed, so that some are unable to commit themselves to non-Cooperation or can commit themselves only at prohibitive cost or are unable to commit themselves as early as others, then it may turn out that one of the stable profitable subgroups is 'forced' into Cooperation and some of the public good is provided. Otherwise there is, as we have seen, a danger that all the players will bind themselves irrevocably to non-Cooperation, or that in the case of a lumpy good so many will bind themselves that the good cannot be provided at all. Recognizing this, risk-averse players might in fact forgo commitment and Cooperate.

It can be argued that forgoing binding in this way is consistent with some well-known principles of decision-making under uncertainty. The pre-game is quite likely to be characterized by uncertainties about the other players' attitudes towards risk and whether they were irrevocably bound to non-Cooperation. Under uncertainty, players might choose to maximize the minimum payoff they could get (the maximin strategy) or choose the strategy which minimizes the difference between the best and worst payoffs obtainable from each strategy (the minimax regret strategy). Adoption of the maximin strategy by all players leads to the Cooperative outcome in Chicken. Use of the minimax regret principle can lead to Cooperative or non-Cooperative choices, depending on the payoff differences. There are, however, well-known doubts about the use of either of these principles, particularly in variable-sum games.

Suppose that each player is not totally uncertain about other players'

Table 2. *Outcomes and i's payoffs*

		Less than $s-1$ others Cooperate	$s-1$ others Cooperate	More than $s-1$ others Cooperate
i's strategy	*C*	public good not provided $-c$	public good provided $b-c$	public good provided $b-c$
	D	public good not provided 0	public good not provided 0	public good provided b

future behaviour but has rather a subjective probability which he puts on each other player committing himself to non-Cooperation. Consider the case of a perfectly lumpy good, which, I have argued, is often best represented by the game of Chicken, and to simplify the analysis assume that any cooperative coalition of at least s players out of the total of N can provide some amount of the public good while larger coalitions cannot provide any more of it. (This model applies to, *inter alia*, the act of voting on committees which was discussed earlier, and it is therefore not surprising that it bears a formal resemblance to accounts of power, such as that given by Shapley and Shubik, which relate power to the question of whether an individual is pivotal in a committee vote.)

Suppose that a player, i, assigns a probability p to any other player Cooperating, that Cooperation costs him c, and that the lumpy good is worth b to him.[7] Player i faces the set of contingencies shown in table 2, which also gives the payoff to each player for each possible outcome. Denote by $P_{<s-1}$, P_{s-1} and $P_{>s-1}$ the probabilities that fewer than $s-1$, exactly s, and more than $s-1$ other players will contribute. Player i's *expected* payoff if he chooses strategy C is the sum of the three payoffs in the top row of table 2 each multiplied by the probability that the outcome in question will occur, that is, by $P_{<s-1}$, P_{s-1} and $P_{>s-1}$ respectively. His expected payoff if he chooses D is calculated similarly. Then the difference between these two expected payoffs – the expected payoff if he chooses C *less* the expected payoff if he chooses D – is:

$$d = -c.P_{<s-1} + (b-c)P_{s-1} + (b-c-b)P_{>s-1}$$

Since the coefficients of c sum to one, this reduces to

$$d = b.P_{s-1} - c$$

which is of course just i's payoff if the public good is provided multiplied by the probability that i will be pivotal in providing it, *less* the cost to i of contributing. Denoting the number of coalitions of size $s-1$ that can be formed from the $N-1$ other players by $\binom{N-1}{s-1}$ in the usual way, the expected payoff differential is

$$d = b\binom{N-1}{s-1}p^{s-1}(1-p)^{n-s} - c$$

Player i will Cooperate just as long as $d > 0$, which implies that the probability that exactly $s-1$ others Cooperate is greater than the cost/benefit ratio c/b. If for example $N=10$, $s=3$ and $p=0.25$, player i's probability of being pivotal is about 0.14, so that b must be about seven times greater than c or more if i is to decide not to commit himself to non-Cooperation.[8]

If, for given values of N, s, b and c, we plot the expected payoff differential as a function of p, we see that it is a unimodal curve with a maximum at $p=(N-1)/(s-1)$, from which it falls monotonically on both sides, as p decreases or increases, to a minimum of $-c$ when $p=0$ and $p=1$. It's clear, then, that d is negative for at least some values of p, whatever the values of N, s, b and c, and may be negative for all values of these parameters. If, for example, $N=5$, $s=3$, $c=2$ and $b=3$ (i.e., the public good is very costly to produce, or little valued by i relative to the value of i's contribution), then there is *no* value of p which makes d positive and hence i will not Cooperate whatever the subjective probability he places on other players Cooperating. But for some values of N, s, b and c, the expected payoff differential d will be positive over some (intermediate) range of values of p. Outside this range, p is either so small that player i expects that not enough others will Cooperate for his contribution to make the difference, or is so large that i expects so many others to Cooperate that his contribution would be redundant.[9]

This analysis of pre-commitment as a risky decision gives us a further reason for believing that some Cooperation will be forthcoming in Chicken games, and hence that in those public goods interactions for which Chicken is the appropriate model *some* amount of the public good will be provided. But unfortunately it has to be said that this analysis has an unsatisfactory implication. Consider the effect on player i's decision to Cooperate of increases in the size of the group, N, and the size of the smallest coalition which is able to provide the public good, s. For given values of b and c, the behaviour of d as N varies depends on the behaviour of the binomial term $\binom{N-1}{s-1}p^{s-1}(1-p)^{N-s}$. The first part of this, the number of subgroups of size $s-1$ that can be drawn from a group of size $N-1$, *increases* with N. Now suppose that player i assumes that *ceteris paribus* each of the other players is *less* likely to Cooperate as N increases and is *more* likely to Cooperate as s increases. Then the probability that any one of the subgroups of size $s-1$ will occur, $p^{s-1}(1-p)^{N-s}$, *decreases* with increasing N.

It turns out that *in some circumstances* increasing the group size N so increases the *number* of subgroups of size $s-1$ in which i's Cooperation is pivotal that this more than compensates for the smaller *probability* that any such subgroup will form, with the result that i is more likely to Cooperate as N increases. Whether or not this happens depends on *how* p declines with increasing N and on the value of $s-1$ relative to that of Np.[10] In a similar way it can be shown that as s increases, the expected payoff differential d can rise or fall (depending on the same two factors).

The upshot is that, when a player assumes every other player is *less* likely to Cooperate as N (or s) increases, under certain conditions he himself is *more* likely to Cooperate as N (or s) increases. We have reached, in other words, the rather unsatisfactory conclusion that i's behaviour as N and s change may be inconsistent with the way he assumes others will behave. (The model is in this sense analogous to the Cournot analysis I shall examine briefly below.)

We do not, however, encounter this problem if player i makes no assumptions about the effects of increases in N or s on p. For some *given* values of N and s (and of b and c), there will be values of p such that his expected payoff from Cooperation is greater than his expected payoff from Defecting. This conclusion, taken together with the (admittedly rather informal) points made in the first two paragraphs of this section, give us grounds for believing that some Cooperation is more likely to occur in games of Chicken than in Prisoners' Dilemmas, if these games are played only once. This conclusion will be reinforced by the analysis in the next section, where I treat games in which each player's strategy set is continuous. But, I must reiterate, the real-world 'games' we are concerned with are rarely played only once, and we should therefore be more interested in the analysis of dynamic or repeated games. The analysis of the iterated Prisoners' Dilemma is the subject of the next two chapters. Of the dynamics of behaviour in iterated Chicken games almost nothing is known – though an encouraging early result from work in progress shows that, contrary to a belief popular amongst students of international relations, it may *not* be rational to try to acquire a reputation for 'toughness' (by making commitments to non-Cooperation) if the game has more than two players.[11]

Continuous strategy sets

In many (but certainly not all) cases of public goods interaction each individual can choose to contribute a continuously variable amount within some range, or choose from a large number of discrete amounts which may be approximated by a continuous model.

Consider, for example, Russell Hardin's model of collective action, introduced in chapter 1. Each individual can choose only between contributing or not contributing one unit of the cost of producing the good (one unit, let us say, of a *numeraire* private good) and every unit contributed produces an amount of the public good with benefit r. Hardin assumed that the benefit to an individual of the public good produced from n units of contributions is nr/N.

Let us now modify this example by allowing each individual to choose to contribute *any* amount from zero to some personal maximum. Then, if the total contribution of all other individuals is C and his own contribution is c, his utility is $(C+c)r/N-c$, so that his utility is a linear function of c, which increases with increasing c if $N < r$, decreases if $N > r$, and remains at a constant level if $N = r$. Thus, when $N > r$, the game is a Prisoners' Dilemma and each individual's utility is maximized if he chooses to contribute nothing, but when $N < r$ he should contribute the maximum possible.

This simple model is not at all typical of public goods interaction. In particular, each individual's utility is a linear function of the total amount (X, say) of public good produced and of the amount of the private good (Y) which he contributes towards the costs of production. Thus, his *indifference curves*, each one a locus of points (X, Y) between which he is indifferent, are linear. The *transformation function*, specifying the quantity of public good which can be produced with a given input of the private good, is also linear.

More generally, we should expect neither of these two functions to be linear. The indifference curves normally will exhibit convexity; that is, as the amount of either one of the goods increases, an additional unit of it requires a smaller sacrifice of the other good in order to maintain utility at the same level. (See, for example, the indifference curves in figure 6.) Also, the transformation function could assume a variety of forms. Over some range it would probably exhibit diminishing marginal returns, that is, as the amount of public good produced increases, the cost of producing an additional unit increases. In the case of lumpy public goods, it would exhibit discontinuities. Let us go on to consider, then, the more general situation in which the indifference curves have the conventional convexity property.[12]

Consider a public for which some good is perfectly indivisible and non-excludable. Consider some member of the public, player i, who may contribute any amount y_i, between zero and some personal maximum $\bar{Y}_i$, of a *numeraire* private good Y_i ('money'). Denote by X the amount of public good produced, and by X_o the amount produced by all the remaining players, whom I shall henceforth refer to as 'the Others'. (Notice that X is the *amount* of public good, not benefit, as in the discussion of Hardin's case above.) Assume that each individual's preferences can be represented by the usual convex indifference curves. If the transformation function, specifying the quantity of public good which can be produced with a given input (y) of the private good, is linear (i.e., an additional unit of y yields the same additional amount, r say, of X at every level of X) and has no discontinuities, then the situation in which i finds himself is that shown at figure 6. If the amount of the public good produced by the Others is *given* and for the time being fixed, then i can decide what is his best course of action. Suppose, for example, that the amount of public good produced by the Others is X_o^1. (Since the good is perfectly indivisible and nobody is excludable, i also consumes X_o^1). Then if i contributes nothing (produces no additional amount of the public good), he is at the point A. If he devotes *all* of his endowment $\bar{Y}_i$ to the public good, he is at point B. The points on the line AB give the whole range of alternatives available to him, *given* the Others' level of production. He will therefore choose the point P_1 at which his utility is maximized – *if* he assumes that the Others' choices will not in turn be influenced by his choice. Similarly, P_o is his optimal response if the Others' production of the good is zero, P_2 if it is X_o^2, and so on. Clearly, the greater the public good return on a unit outlay of the private good, the more of the public good i will choose to produce for a given production by the Others.

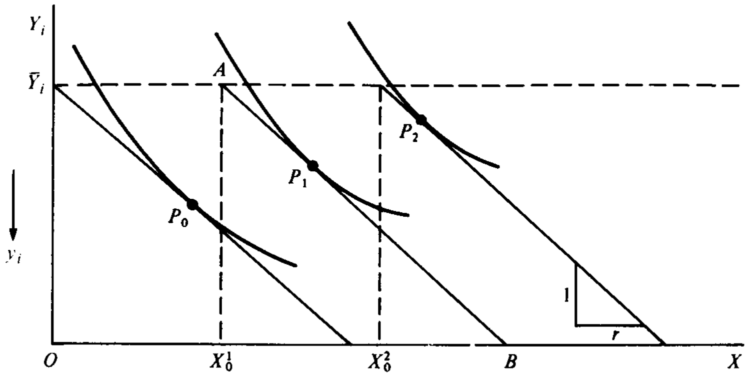


Figure 6

It can be seen that, in this example, the more Others contribute, the *less* will the individual in question contribute. In this respect i's preferences are like those of a Chicken game.

But transformation functions are unlikely to be linear. In many cases they will exhibit diminishing marginal returns, as in figure 7; or the amount of public good which can be provided will at first increase only slowly with increasing contributions, then much faster, then fall off with diminishing marginal returns, as in figure 8. (The shape of the transformation function facing i changes of course as Others provide more of the public good. In effect, each transformation curve in these figures is a lower portion of the curve to its left). If the good is lumpy, the transformation function will be a step function, of which one plausible form is shown in figure 9. Here, the public good cannot be provided at all

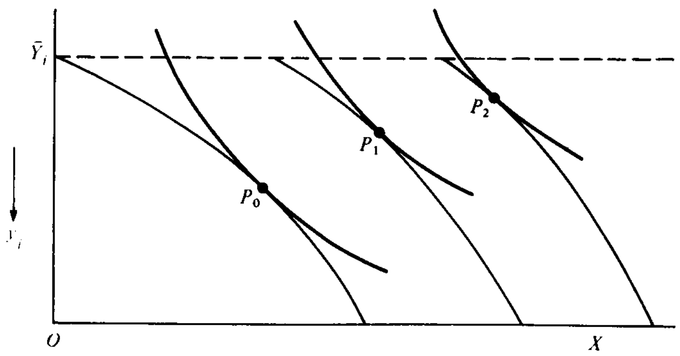


Figure 7

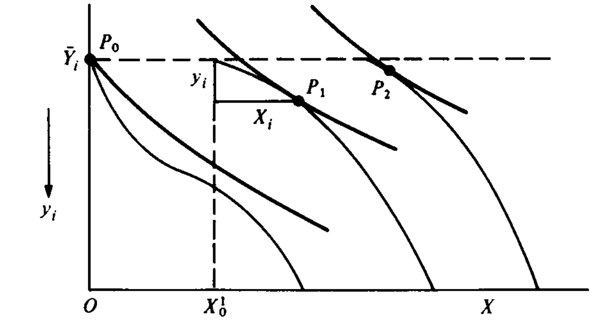
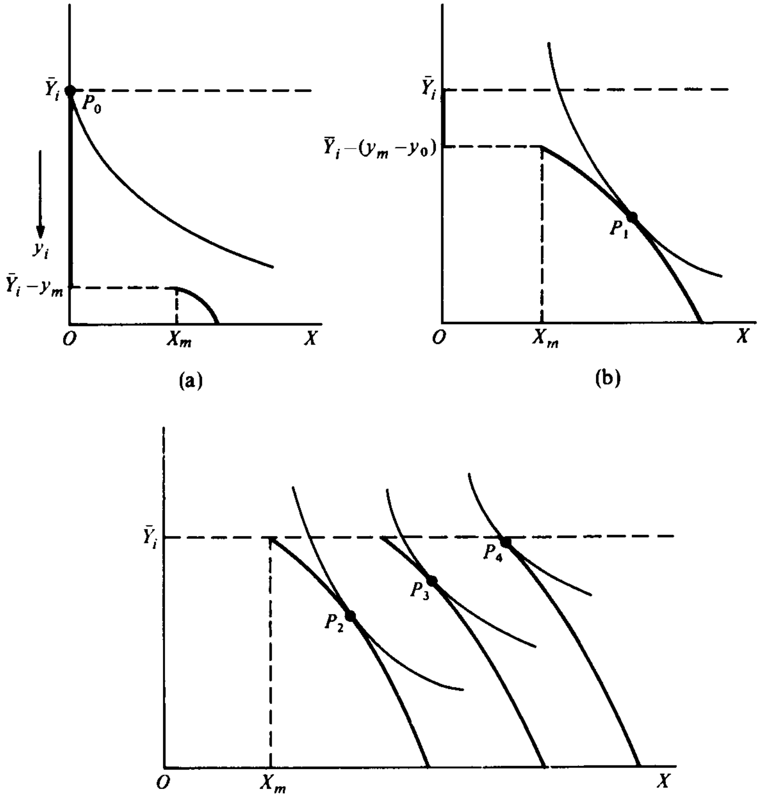


Figure 8



(a)

(b)

(c)

Figure 9

if total contributions are less than some threshold (y_m, say), at which the minimum 'lump' of the public good (an amount X_m) can be provided, and beyond which increasing contributions yield diminishing returns of public good. (Another possibility is that the public good can be provided at only one level – a one-step pure lumpy good – in which case the curvilinear parts of the transformation functions in figure 9 are vertical lines.)

Figure 9 assumes that $y_m < Y_i$, that is, the minimum that must be contributed if any of the public good is to be provided is less than player *i*'s endowment (the most he can contribute). This ensures that $\bar{Y}_i - y_m$ is positive, so that if *i* contributes enough he alone can cause some of the public good to be provided. In figure 9(a) the Others' contribution (X_o) is zero. So if *i* contributes less than y_m, none of the public good is provided, and therefore part of the transformation function is the segment of the Y_i axis as shown. When *i* contributes y_m or more, some amount of the public good is provided, as shown by the curvilinear part of the transformation function. In figure 9(b) the Others have contributed a positive amount (y_o say) but not enough to pass the threshold, so that none of the public good is provided until *i* has contributed enough ($y_m - y_o$) to bring the total contributions to the threshold y_m. In figure 9(c) the Others' contributions have reached the threshold y_m exactly (the left-most transformation curve), at which point an amount X_m of the public good is provided if *i* contributes nothing, or they have passed it (the remaining curves). Note that the lumpy form shown in figure 9 is a limiting case of the transformation curve shown in figure 8.

The earliest phase of the sequence in figure 9 has to be modified if $y_m \geqslant \bar{Y}_i$, that is, the minimum that must be contributed if any of the public good is to be provided is at least as great as *i*'s endowment. For as long as the Others' total contribution falls short of y_m by at least $\bar{Y}_i$, then no matter how much player *i* contributes, he cannot reach the threshold y_m, so cannot cause any of the public good to be provided. If the Others contribute nothing, or any amount less than or equal to $y_m - \bar{Y}_i$, the transformation function facing player *i* is the whole of the segment $O\bar{Y}_i$ of the Y_i axis. When the Others' contributions exceed $y_m - \bar{Y}_i$, *i*'s transformation function is first as in figure 9(a), then as in figures 9(b) and (c) as the Others' contributions increase.

Let us look now at the pattern of *i*'s optimal responses as the Others' contributions increase. The first point to note is that, for *any* of these transformation functions, if i's indifference curves are 'sufficiently flat' – that is, the individual's valuation of the public good is sufficiently low relative to his valuation of his private good – then his optimal response to any level of contribution by the Others is a zero contribution; so that, if this is so for every individual, the game is a Prisoners' Dilemma. (How 'flat' the indifference curves must be depends of course on the shape of the transformation function.)

If the indifference map is not like this, then the patterns of optimal response most likely to occur are of two kinds. The first, which is Chicken-like, has already been encountered in figure 6 with a linear transformation function: here, the more Others contribute, the less will i want to contribute (and if Others contribute enough, i will want to contribute nothing). This pattern is also illustrated in figure 7, and it is easy to see how it could occur (with 'steeper' indifference curves) in figure 8. For the lumpy good shown in figure 9, it could arise only if the threshold y_m was sufficiently small so that a sufficiently 'steep' indifference curve in figure 9(a) would be tangent to the curvilinear part of the transformation function. The second pattern is shown in figure 9 and is likely to arise only where the transformation function corresponds to a step or lumpy good (of which the function in figure 9 is an example) or is of the sort shown in figure 8 (of which figure 9 is a limiting case). In this case, i's optimal response is to contribute nothing if Others contribute nothing (P_o in figure 9(a)), but to make a contribution if the Others' contributions exceed some minimum (P_1, P_2, etc. in figure 9(b) and (c)). In this respect the resulting game (if every individual has a similar response pattern) is *Assurance-like.* But when i does contribute, his contribution declines with increases in the Others' contributions. In this respect, the game is *Chicken-like.* What is happening here is that, because of the shape of the transformation function (reflecting the fact that little (figure 8) or none (figure 9) of the public good can be provided out of small contributions, but beyond some threshold a small increase in contributions yields a substantial increase in public goods provision), an individual may find that if the Others are contributing enough (but not too much), a small contribution from him yields so much more of the public good that he is more than compensated for the costs of his contribution. In figure 8, for example, if Others contribute an amount in the region of X_0^1, a small contribution (y_i) from i yields a great increase (X_i) in the public good. Similarly in figure 9(b), when Others have contributed most of the minimum necessary (y_m) to start production of the public good, a small additional contribution from i takes the group over the threshold (to the point P_1 for example).

This *Assurance/Chicken* pattern is an intuitively plausible one, and where contributions vary continuously it is likely to arise in just those situations (discussed earlier) which would be Chicken games if the individual could choose only between a zero contribution and a single fixed level of contribution. In the flood control and irrigation case, for example, if each cultivator could choose *any* level of contribution (work effort) up to some maximum, then the transformation function is likely to be of the kind shown in figures 8 or 9; so that, unless every individual values the public good (irrigation, flood control, etc.) so little as to make the resulting game a Prisoners' Dilemma, which is unlikely in this case, there are two possibilities: (a) the Chicken-like case in which each individual values the public good so much that he is able and prepared to provide some of it when Others provide none, but will contribute less as Others contribute more; or (b) the combined Assurance/Chicken case in which each individual does not value the public good highly enough to find it worthwhile to provide some of it alone, but will contribute to its provision if Others do, though contributing less as Others contribute more. In the irrigation and flood control example, the first of these possibilities is perhaps less likely than the second, because although each individual may value this public good very highly indeed he is unable alone to provide any of it (figure 9) or enough of it to make it worth his while (figure 8).

These are not the only possible response patterns, of course, though they are probably the ones most likely to occur.

In chapter 1 I suggested that *indivisibility* and *nonrivalness* should be distinguished, though they are commonly not. The difference between them can be clearly seen in terms of the diagrams we are using here. If a good is not perfectly indivisible, then as group size, N, increases, the amount available for an individual's consumption decreases. Since the transformation function represents the consumption *possibilities* for an individual, given the amounts of public good already provided by Others and by himself, its shape would change as N varied. In fact, as N increased in the case of an imperfectly indivisible good, the amount of the public good available to i (for a given total contribution of the private good) would decrease (so the transformation curve would rotate or shift in a southwesterly direction).

On the other hand, if some rivalness was present, the indifference maps should change as N varied, becoming 'flatter' with increasing N to reflect the lower value that *a given quantity of the public good* has to the individual in question as more consumers are present.

The effect of an increase in N on the individual's contribution (for a given contribution by the Others) need not be the same in the two cases.

Cournot analysis

We saw in the last section that an individual could determine his optimal level of contribution – given the total amount of public good provided by the remaining individuals and assuming that their choices in turn are not influenced by his decision, that is, that each individual behaves non-strategically (such behaviour is known as Cournot behaviour). Suppose now that there are just two individuals and that for each of them we can determine an optimal response to each level of public good provided by the other. Let $X_1^0(X_2)$ denote individual 1's optimal response for a given value of X_2, the amount of the public good provided by individual 2. Define $X_2^0(X_1)$ similarly. These *response functions* or *reaction curves* can take many forms. For the Chicken-like cases illustrated in figures 6 and 7 above, typical shapes of the reaction curves are those shown in figure 10.

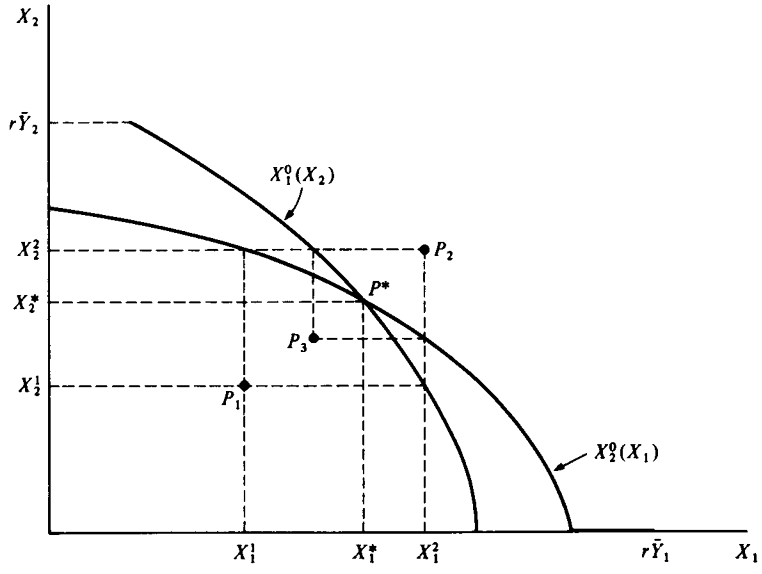


Figure 10

Assuming still that each individual behaves non-strategically, suppose that initially the two individuals choose to produce amounts X_1^1 and X_2^1 of the public good (the point P_1 in figure 10). Then each realizes that his own production is not optimal, given the other's choice. Individual 1 will increase his production to $X_1^0(X_2^1)=X_1^2$, and individual 2 will increase his to X_2^2. This brings them to P_2. But here, too, each has an incentive to alter his level of production, and they will move to P_3. This 'process' will converge to the point P^* in figure 10, the point at which the two reaction curves intersect, and P^* is the only point at which neither individual has an incentive to change his production level unilaterally. It is, in other words, an equilibrium. This equilibrium need not be Pareto-optimal.

On the assumption of non-strategic behaviour, an individual's optimal response to a given level of provision of the public good by Others – and therefore his entire reaction curve – would be the same no matter how many other individuals there were. If we also assume that all individuals have identical preferences and the same initial endowments of private good that can be devoted to production of the public good, then it is possible to examine the movement of the (Cournot) equilibrium as the size of the group increases. This has been done by John Chamberlin and Martin McGuire, who have shown that if the good exhibits pure jointness or indivisibility and there is perfect nonrivalness, then the amount contributed by each individual at the Cournot equilibrium declines with increasing group size, tending to zero as N approaches infinity, but that provided the public good is not an inferior good[13] for any individual the *total* amount of the public good provided at the equilibrium *increases* with group size.[14] (This result depends critically on the assumption that the reaction curves do not vary with N – which holds only if the good is purely indivisible and perfectly nonrival *and the total costs of providing the public good do not rise with N.* This second condition is not mentioned by Chamberlin or McGuire.)

If, on the other hand, the public good is not purely indivisible or there is some degree of rivalness (though the good is still non-excludable), then the individual's equilibrium production decreases as N increases, but the group's total production may increase *or* decrease depending on how the reaction curves vary with N.[15]

These results for the case of non-strategic or Cournot behaviour are consistent with those stated in the discussion of Olson's 'size' argument in chapter 1. But in my view we should not attach much significance to them, for three reasons. First, as it is conventional to point out, the Cournot analysis is based on the quite unacceptable assumption that each individual reacts to what others do while assuming that they do not react to what he does, that is, that in reacting to their choices he can ignore the effect of his actions on theirs. Second, the analysis is entirely static. The reactions and counter-reactions of which it speaks constitute only a sort of pseudo-dynamics; they are merely conjectural, taking place, as it were, only in the heads of the players. As I have argued already, public goods provision is generally a *process*; interaction, usually strategic, takes place *in time*. This should be modelled explicitly (as it is in the analysis in the next two chapters). Third, in many important public goods interactions, the reaction curves will not resemble those shown in figure 10 and in some (perfectly plausible) cases there will be multiple local equilibria and the Cournot analysis will provide no reason to expect that any one of them will be the outcome. For example, if in a two-person situation the transformation function and indifference maps are such as to produce the Assurance/Chicken pattern of optimal responses illustrated by figures 8 and 9 above, then the two reaction curves resemble those in figure 11. In this case, the points *O* and *P** are locally stable. But starting at some points, such as *A* and *B* in figure 11, the Cournot series of reactions will not converge on *O* or *P** or on any other point.

A summary remark

The general thrust of this chapter, with or without the Cournot analysis, has been that in public goods interaction the individuals' preferences at any point in time are not necessarily those of a Prisoners' Dilemma game. This is true of both two-person and *N*-person games and of cases where strategy sets are continuous as well as those where the players have only two strategies available to them. I have argued in particular that important classes of public goods provision problems are better represented by Assurance and especially Chicken games and in the continuous case by games that are Chicken-like or like a hybrid of Assurance and Chicken. In these cases, arguably, if the games are played only once, *some* cooperation is more likely to be forthcoming than in cases for which the Prisoners' Dilemma is the appropriate model.

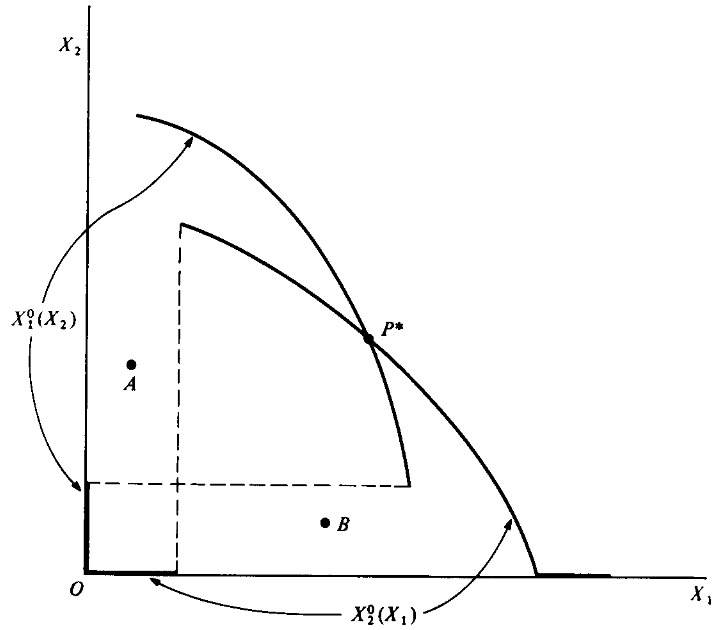


Figure 11 Reaction curves for an Assurance/Chicken Game

In the next two chapters, however, I shall assume the worst: that preferences at any point in time are indeed those of a Prisoners' Dilemma game. But then I shall go on to consider the possibility of cooperation when this game is repeated.

3. The two-person Prisoners' Dilemma supergame

The treatment of the problem of public goods provision in the last chapter was entirely static. It was concerned only with preferences at one point in time, and conclusions about public goods provision were derived solely from these static preferences. Individuals were supposed, in effect, to make only one choice, once and for all (a choice of how much to contribute to the provision of the public good). Olson's *Logic of Collective Action* and other studies referred to in the first two chapters are static in this way.

Needless to say, it is not always like this in the real world. With respect to most public goods, the choice of whether to contribute to their provision and of how much to contribute is a recurring choice; in some cases it is a choice that is permanently before the individual. This is true of the choice of how much to exploit the 'common': how many whales to take in each year, how much to treat industrial waste before discharging it into the lake and so on. It is also true of the individual's choice of whether or not to behave peaceably, to refrain from violence, robbery and fraud and so on.

I propose to treat these recurring choices in the context of a supergame.

Supergames

The remarks and definitions in this section apply both to the two-person analysis to which the remainder of this chapter is devoted and to the N-person analysis in the following chapter.

A *supergame* is simply a sequence of games. The games in the sequence are called the *constituent games* of the supergame. In this book I shall consider only supergames which are iterations of a single game. The

constituent game will be a Prisoners' Dilemma in which two strategies are available to each player: to Cooperate (C) or to Defect (D). In each constituent game of this Prisoners' Dilemma supergame the players make their choices simultaneously (that is, in ignorance of the other players' choices in that game), but they know the strategies chosen by all the players in all previous games.

The Prisoners' Dilemma is by definition a non-cooperative game. The Prisoners' Dilemma supergame is thus also a non-cooperative game. Either agreements may not be made (perhaps because communication is impossible or because the making of agreements is prohibited) or, if agreements may be made, players are not constrained to keep them. It is the possibility of cooperation in the *absence* of such constraint that I am interested in here.

In this dynamic setting it is possible for an actor to make his choices dependent on the earlier choices of other players. In particular, cooperation could be made conditional on the cooperation of the other player or players. This idea will be central in the analysis which follows. It will emerge, as one would intuitively expect, that if cooperation is to be sustained amongst rational egoists, it must be through the use of conditionally cooperative strategies.

The constituent game of a supergame will be thought of as being played at regular discrete intervals of time, or one in each time period. Each player receives his constituent game payoff at the end of each time period. The supergame is assumed to 'begin' at $t=0$ and the constituent game payoffs to be made at $t=1, 2, 3, \ldots$

It is reasonable to assume that the present worth to a player of a future payoff is less the more distant in time the payoff is to be made. Specifically, I make the usual assumption that future payoffs are discounted exponentially. Thus the value at time $t=0$ of a payoff X_t to be made at time t (at the end of the t^{th} game) is $X_t a_i^t$. The number a_i is called the *discount factor* of player i, and its complement $1-a_i$ is the discount *rate*.[1] It is assumed that $0 < a_i < 1$. Thus the present value of a finite payoff from a game infinitely distant in the future is zero. The discount rates, though they may differ between individuals, are assumed to remain constant through time. An important consequence of this assumption (given that the constituent games do not change over time) is that for each player the supergame in prospect looks the same at any point in time.

The processes in which I am interested are of indefinite length. They are represented here by supergames which can be interpreted either as being composed of a countably infinite number of constituent games or as having a known and fixed probability of terminating in any time period.

These two assumptions – of discounting and indefinite length – seem to me to be appropriate ones for the problems I am interested in here, and indeed for most other social and economic processes which could be modelled by supergames. Whether or not one thinks the future *should* be discounted (especially in such contexts as the conservation of non-renewable resources or the dumping of nuclear wastes), the idea that rational egoists playing supergames of indefinite length might actually place as much value on a payoff to be received far into the future as on the same payoff to be received immediately is quite implausible.[2]

If the supergame has only a *finite* number of constituent games (and the players know this), the 'dilemma' remains, in the sense that Defection in every constituent game is the only undominated strategy, no matter what the constituent game payoffs are. Consider a two-person Prisoners' Dilemma game iterated T times. At the start of this supergame, each player knows that in the final game (there being no possibility of reprisals), Defection is his only undominated strategy, so he will choose it; and he knows that for the same reason the other player will choose D. The outcome of the final game is therefore a foregone conclusion. The penultimate, or $(T-1)^{\text{th}}$ game, is now effectively the final game and the same argument applies to it. Each player will choose D and expect the other player to do likewise. Similarly for the $(T-2)^{\text{th}}$ game, and so on, back to the first game.[3]

A *supergame strategy* is a sequence of strategies, one in each constituent game. In the Prisoners' Dilemma supergame, the strategy in which C is chosen in every constituent game will be denoted by C^∞; that in which D is chosen in every constituent game will be denoted by D^∞. Other supergame strategies of special interest will be introduced below. A *strategy vector*, in either a constituent game or in a supergame, is a list (an ordered n-tuple) of strategies, one for each player.[4]

The *outcome* of a constituent game is the actual state of affairs at the end of the game. An outcome of a supergame is a sequence of outcomes, one for each constituent game. In the constituent games and supergames considered here, an outcome is uniquely determined by the strategies actually chosen by the players.

Associated with each strategy vector in a constituent game is a *payoff vector*, which is a list (an ordered n-tuple) of payoffs, one for each player. A payoff is to be thought of as a quantity of some basic private good, such as money, or amounts of several private goods reduced to a single quantity of some *numeraire*, such as money. In this chapter and the next, each player is assumed simply to seek to maximize his own payoff, and his payoff scale is assumed to be *cardinal* (that is, it has an arbitrary zero and unit and can be replaced by any positive linear transformation of itself). Here the payoffs may be identified with 'utilities', in the sense that a player (strictly) prefers one outcome to another if and only if the first yields a greater payoff (utility) than does the second and he is indifferent between them if and only if they yield equal payoffs. But in a later chapter on altruism this identification is not made, for here a player's utility is assumed to be a function of the payoffs of other players as well as his own.

A *supergame payoff* to a player is the sum of an infinite series whose terms are his payoffs in the ordinary games. The discounted value of this payoff at $t=0$ is thus $\Sigma_{t=1}^{\infty} X_t a_i^t$, where X_t is i's payoff at time t (his payoff from the game in period t). Since $0 < a_i < 1$, this infinite series converges (that is, the supergame payoff is finite) for any sequence of payoffs $\{X_t\}$, just as long as each X_t is finite (as it always will be here). In the two-person case, the supergame payoffs can be exhibited in a payoff matrix, as in the ordinary game.

The concepts of dominance and Pareto-optimality have already been introduced (in chapter 1). The definitions given there also apply, *mutatis mutandis*, to supergames, but a few more terms are needed. The definitions which follow apply to both ordinary games and supergames.

An outcome is said to be *Pareto-preferred* to another if and only if at least one player (strictly) prefers the first to the second and no player (strictly) prefers the second to the first.

An *equilibrium* is defined as a strategy vector such that no player can obtain a larger payoff using a different strategy while the other players' strategies remain the same. An equilibrium, then, is such that, if each player *expects* it to be the outcome, he has no incentive to use a different strategy. Thus, if indeed every player expects a certain equilibrium to be the outcome, then it is reasonable to suppose that this equilibrium will in fact be the outcome. But a player may have reasons for expecting that a certain equilibrium will not be the outcome. Then he might not use his equilibrium strategy and the equilibrium will not be the outcome.

This possibility is important, as we shall see, in the study of supergames. For whereas in the Prisoners' Dilemma ordinary game there is only one equilibrium and there is no reason for a player not to expect it to be the outcome, in Prisoners' Dilemma supergames there are generally several equilibria and the question arises whether some of them may be eliminated as possible outcomes because at least one of the players does not expect them to occur.

For convenience, the following expressions are sometimes used in this chapter and the next. A strategy vector is said to be *always* an equilibrium if and only if it is an equilibrium no matter what the ordinary game payoffs are (as long as they satisfy the inequality which makes the ordinary game a Prisoners' Dilemma) and no matter what values the discount factors assume (as long as each a_i satisfies $0 < a_i < 1$). A strategy vector is *sometimes* an equilibrium if and only if it is an equilibrium for some but not all values of the ordinary game payoffs and the discount factors. If a strategy vector is neither always nor sometimes an equilibrium, then it is said to be *never* an equilibrium.

The general purpose of the remainder of this chapter is to study the conditions under which cooperation of various kinds will occur in Prisoners' Dilemma supergames. The approach will be to determine which strategy vectors are equilibria and under what conditions, and, where there are multiple equilibria, which of them is likely to be the outcome of the game. The remainder of this chapter[5] will be concerned with the two-person supergame, and the N-person game will be tackled in the following chapter.

Unconditional Cooperation and Defection

Consider then the supergame consisting of iterations of the two-person Prisoners' Dilemma game whose payoff matrix is:[6]

	C	D
C	x, x	z, y
D	y, z	w, w

where $y > x > w > z$. Rows are chosen by player 1, columns by player 2.

The first, and depressing, thing to note about this supergame is that it never pays either player to change his strategy unilaterally if both players are playing D^∞, the strategy of choosing D in every constituent game regardless of the other player's previous choices; that is, *mutual unconditional Defection is always an equilibrium.* This is easily demonstrated. Any strategy *other* than D^∞ must either result in D being played on every move (in which case switching to it unilaterally from D^∞ yields the same payoff) or in C being played in one or more constituent games. Such a switch has no effect on the other player, since he Defects unconditionally. So, in these C-moves, the player who switches gets less (z rather than w) than he would have done if he'd stuck to D^∞, while in all the remaining moves he gets the same (w). This is so regardless of the values of the constituent game payoffs and of the discount rates. So (D^∞, D^∞) is always an equilibrium. It is therefore a candidate for the outcome of the supergame. The conditions under which this disastrous result would occur are examined below.

We note next that (C^∞, C^∞) is *never* an equilibrium, for either player can obtain a greater payoff by switching unilaterally to D^∞.

In fact, any strategy pair in which *either* player chooses C^∞ is never an equilibrium. Against C^∞, another player can always gain by changing his strategy to D^∞, since whatever he changes to will have no effect on the first player, whose choices are unconditional. And if one player is already using D^∞, then the C^∞ player can gain by switching to D^∞. More generally, *any* strategy which results in C being played in any constituent game is never an equilibrium when paired with D^∞. This will include any of the conditionally cooperative strategies to be defined below. In any constituent game in which the strategy specifies a C move, the player could do better by switching to D when playing against D^∞. In other words, *it doesn't pay to Cooperate against D^∞.*

The possibility of conditional Cooperation

Both C and D are *unconditional* strategies. Since a C^∞ player persists in playing C regardless of the other player's moves, he can be taken advantage of. Suppose he instead adopts a *conditionally* cooperative approach, playing C only if the other player does too. More precisely, suppose he chooses C in the first constituent game, and in successive games chooses C if and only if the other player chose C in the preceding game. Call this strategy B. It has often been referred to as the 'Tit-for-Tat' strategy. Of course, against a player who Defects unconditionally, playing B produces a worse outcome than would playing D^∞. But if both players use B, then mutual Cooperation is the outcome in every constituent game. Can this be sustained; that is, is (B, B) an equilibrium?

Let us first see whether it pays either player to defect unilaterally from B to D^∞, given that the other player is using B. The result of such a switch is that the other player, after playing C in the first constituent game, observes that the first player chose D in that game and therefore chooses D in the second game, and similarly in every succeeding game. His conditional Cooperation, in other words, 'collapses' immediately. Now whether such a switch yields any gain depends on his *discount rate*, since in making this switch the player *gains* in the first time period (the one in which he switches) but *loses* in every period thereafter – relative, that is, to the payoffs he would have received had he stuck to strategy B. This would only produce a net gain if he valued later payoffs so much less than earlier ones that the gain in the first period outweighed the losses in all later periods. Let us derive the precise form of this condition.

If, against a player using B, player i (with discount factor a_i) also uses B, his payoff in each constituent game is x, so that his discounted supergame payoff is the sum of the infinite series $x(a_i+a_i^2+a_i^3+\ldots)$, which is $xa_i/(1-a_i)$. If he switches unilaterally to D^∞, his payoff in the first game is y and in every succeeding game w, so that his supergame payoff is $ya_i+wa_i^2/(1-a_i)$. So the switch does *not* yield a gain if and only if this second payoff is no greater than the first. When this inequality is rearranged, we find that we must have:

$$a_i \geqslant \frac{y-x}{y-w} \tag{3.1}$$

or, in terms of the discount *rate*,

$$1-a_i \leqslant \frac{x-w}{y-w}$$

So: if unilateral defection from (B, B) to D^∞ is not to pay, the discount rate must not be too great. How great depends on the constituent game payoffs. In particular, it is intuitively obvious, and condition (3.1) shows formally, that the smaller the 'instant' gain from defection – the difference $y-x$, which we could call the player's *temptation* – the less likely, other things being equal, will unilateral defection to D^∞ yield a gain in the supergame.

An Assurance game

Suppose for the moment that B and D^∞ are the only strategies available to each player or the only ones they consider, and suppose that condition (3.1) is satisfied for both players, so that (B, B) is an equilibrium. More strongly, suppose that the inequality in (3.1) is strict, so that (B, B) is *strictly* preferred by player 1 to (D^∞, B) and by player 2 to (B, D^∞). Then it is easily verified that the ordinal preferences among the four possible outcomes are:

	B	D^∞
B	4, 4	1, 3
D^∞	3, 1	2, 2

(where as usual a higher number represents a more preferred outcome). This makes the supergame an *Assurance* game (as defined in chapter 2). There are then two equilibria, (D^∞, D^∞) and (B, B), but since one of them, (B, B), is preferred by both players to the other, neither player would expect (D^∞, D^∞) to be the outcome, so that (B, B) would be the outcome (because the point about an equilibrium of this kind is that *if* every player *expects* it to be the outcome – which means that every player is expected to play the appropriate strategy – then it *will* be the outcome).

But if (B, B) is *not* an equilibrium, this reduced supergame is itself a Prisoners' Dilemma, and then of course (D^∞, D^∞) is the outcome.

Conditions for (B, B) to be an equilibrium

We have shown that under certain conditions (B, B) is robust against unilateral defections to D^∞. But the number of possible strategies in any supergame is infinite. If defection by either player from (B, B) to D^∞ does not pay, might it nevertheless pay to defect to some other strategy? Consider the supergame strategy which, like B, is a tit-for-tat strategy, but unlike B begins with D in the first constituent game. Call it B'. If one player (i) switched from B to B' while the other (j) played B, then in the sequence of moves which would result, (D, C) would *alternate* with (C, D):

player i (B'): *DCDC* . . .
player j (B): *CDCD* . . .

The same sequence would result, of course, if player i switched to the strategy of unconditionally alternating between D and C after playing D in the first game. Player i's discounted supergame payoff is now:

$$ya_i + za_i^2 + ya_i^3 + za_i^4 + \ldots$$

which sums to

$$\frac{ya_i}{1-a_i^2} + \frac{za_i^2}{1-a_i^2}$$

or $(y+za_i)a_i/(1-a_i^2)$. Such a switch from (B, B) to B' would not yield player i a gain if and only if this sum is no greater than his payoff from (B, B), which is $xa_i/(1-a_i)$. On rearranging, this condition becomes

$$a_i \geqslant \frac{y-x}{x-z} \qquad (3.2)$$

Note that (3.2) neither entails nor is entailed by (3.1). So both conditions must be included in the necessary conditions for (B, B) to be an equilibrium. Or combining them, we can say that a *necessary* condition for (B, B) to be an equilibrium is that both players' discount factors, a_1 and a_2, must be at least as big as the larger of the two ratios specified in (3.1) and (3.2).

Is this a sufficient condition? It turns out that it is. At an equilibrium, each player's strategy is the 'best response' to the other player's strategy, in the sense that there is no strategy which it would be better to use than the equilibrium strategy, given that the other player will use *his* equilibrium strategy. Suppose that one player is using strategy B. His first move is therefore C. Now consider the other player's response to B.

Suppose that, whatever is the best response to B, it begins with C in the first constituent game. Then the B-player's move in the second game is C. So if the best response to B begins with C in the first game, then it must also play C in the second game. This is because (1) for each player the game ahead is the same at any point in time (since both the discount rates and the constituent game payoffs were assumed to remain constant), and (2), a player using strategy B is responsive to the other player's choices in the preceding game only. It follows that, if the best response to B begins with C, it must play C in every constituent game.

Suppose now that, whatever is the best response to B, it begins with D. (It follows that if in any later game the B-player chooses C, the best response will play D in that game). Then the B-player's move in the second game is D. There are now two possibilities for the best move in the second game:

(i) Suppose that whatever is the best response to B, it plays C in any game in which the B-player chooses D. Then the B-player's next move (in the third game) is C. . . so that the best response to B plays D in this game. And so on. This generates the pattern of alternation between (C, D) and (D, C) throughout the supergame.

(ii) Suppose instead that the best response to B would play D in any game in which the B-player chooses D. Then the B-player's next move (in the third game) is D. So again the best response must play D in the third game. And so on. This generates a best response in which D is chosen in every constituent game.

This exhausts the possibilities. Against B, the best response *must* be to play C in every game (as would happen if B were played) *or* to alternate between D and C beginning with D (as would happen if B' were played) *or* to play D in every game. No other response can do better against B than the best of these three. It follows that if a player cannot gain by switching unilaterally from (B, B) to B' or D^∞, then no other strategy will yield a gain. Thus, if conditions (3.1) and (3.2) – which guarantee that (B, B) is stable against defections to D^∞ and B' – are satisfied, then (B, B) is an equilibrium.

It has been shown, then, that a *necessary and sufficient condition for* (B, B) *to be an equilibrium is that each player's discount factor is no less than the larger of* $(y-x)/(y-w)$ *and* $(y-x)/(x-z)$.

Of course, this result does not imply that when this condition is satisfied, (B, B) is the outcome of the game. I return to this matter below.

Axelrod's tournaments

A similar result to the one just proved can be found in Axelrod's book *The Evolution of Cooperation*. His proof of necessity is essentially the one given above, which follows the analysis in *Anarchy and Cooperation.* Although in the earlier treatment (B, B) was shown to be stable against unilateral defections to the class of strategies A_k to be discussed below, as well as defections to D^∞ and B', I did not prove sufficiency. Axelrod's 'proof' of the sufficiency part[7] is incomplete (at least); he may have had in mind the proof I gave here but this is unclear from what he actually says.

Axelrod's result actually concerns, not the (Nash) equilibrium of the strategy pair (*B*, *B*), but the 'collective stability' of the strategy *B* (which he calls TIT-FOR-TAT). The notion of collective stability derives from the concept of an 'evolutionarily stable strategy' introduced into evolutionary biology by Maynard Smith, and is defined in a model which supposes that there is a population of individuals all using a certain strategy (*S*, say) and asks whether it can be 'invaded' by a single mutant individual using some other strategy (*S'*). The mutant strategy is said to *invade* the native strategy if it can do better playing repeatedly against a native than a native can do against another native. Then, a strategy is said to be *collectively stable* if no strategy can invade it.

Thus, a collectively stable strategy is, as Axelrod puts it, 'in Nash equilibrium with itself', that is, if *S* is a collectively stable strategy then (*S*, *S*) is an equilibrium. But of course an equilibrium need not consist of a pair (or a population) of identical strategies (and in what follows we shall see that pairs of different strategies can be equilibria under certain conditions in the two-person supergame, and in the next chapter we shall establish that there are equilibria in the *N*-person supergame which are composed of several different strategies). Nash equilibrium, then, is not the same thing as collective stability, and Axelrod's 'Characterization Theorem' is not very helpful in carrying out a full equilibrium analysis.

Axelrod, in fact, confines his attention to *tournaments*, in which individuals play in *pairs*. This is true both of his theoretical analysis, which is based, as we have seen, on the notion of a collectively stable strategy, and of the round-robin computer tournament he conducted. In the latter, a number of game theorists, economists, etc., submitted strategies, each of which was paired against itself and against each of the others in a Prisoners' Dilemma supergame. The strategies were then ranked according to their aggregate performance. (TIT-FOR-TAT – the strategy I have called *B* – won, and in a second competition, involving strategies submitted in the light of the results of the first competition, it won again.)

Axelrod comes to the same *general* conclusion we arrive at here (and which was at the heart of the analysis of the Prisoners' Dilemma supergame in *Anarchy and Cooperation*), namely that 'the two key requisites for cooperation to thrive are that the cooperation be based on reciprocity, and that the shadow of the future is important enough to make this reciprocity stable.'[8]

But is his approach, based on the idea of the tournament and the concept of a collectively stable strategy, to be preferred to an analysis using the notion of a (Nash) equilibrium? I think not. Pairwise interaction may be characteristic of non-human populations (though even this is doubted by Maynard Smith himself), but it certainly does not characterize most human interactions which give rise to collective action problems. These of course generally involve more than two individuals and, especially where the provision of public goods is at stake, an individual's behaviour typically depends on the whole aggregate pattern of behaviours of the rest of the group. For example, his decision whether or not to cooperate in the provision of a public good would generally be contingent on there being *enough others* cooperating. Situations of this kind cannot be characterized in terms of pairwise interactions. Even where, in the real world, interactions are truly pairwise, they are most unlikely to take the strange form assumed by Axelrod: his analysis hinges on the assumption that an individual will play out the whole of an infinite supergame with one other player, or each player in turn, rather than, say, ranging through the population, or part of it, playing against different players at different times in the supergame (possibly playing each of them a random number of times).[9]

Axelrod, admitting that his book 'will examine interactions between just two players at a time', suggests that 'situations that involve more than pairwise interaction can be modelled with the more complex *n*-person Prisoner's Dilemma',[10] but does not attempt the analysis himself. We shall take up the study of *N*-person Prisoners' Dilemmas in the next chapter.

Coordination equilibria

It is worth mentioning in passing that *if* (*B*, *B*) is an equilibrium in the two-person Prisoners' Dilemma supergame it is also a *coordination equilibrium*. A coordination equilibrium is a strategy pair such that either player is made no better off, not only if he himself unilaterally changes strategy, but also if the *other* player changes strategy. Consider (*B*, *B*). In the case of the other player defecting to D^{∞}, the effect on the non-defecting player is the same as it would have been if *he* had defected, except in the first constituent game, where now he gets even less than he would have done had he defected (z rather than y); so that if his own defection makes him no better off, the other's defection certainly will not.

Similar remarks apply to changes to other strategies (except where such a change produces the same sequence of constituent game outcomes): for example, if defection to B' by either player makes him no better off, then nor will he be made better off by the other player's defection to B', since the two resulting sequences of constituent game outcomes are identical – alternation between (C, D) and (D, C) – except that the sequence begins with (D, C) if *he* defects and (C, D), which is worse for him, if the *other* defects. Thus, if (B, B) is an equilibrium, it is a coordination equilibrium. This is not, of course, true of (D^{∞}, D^{∞}), which is always an equilibrium but never a coordination equilibrium.

Russell Hardin believes that the fact that (B, B) and other strategy vectors are *coordination* equilibria makes an important difference to the explanation of behaviour in Prisoners' Dilemma games. A coordination equilibrium, he says, is even more likely to be the outcome than a mere equilibrium because it is 'supported by a double incentive to each player', for each player has an interest in himself conforming with the equilibrium and an interest in the other player conforming as well.[11]

Actually, as we have seen, in the Prisoners' Dilemma supergame with discounting, (B, B) need not even be an equilibrium. But we have to assume that Hardin has in mind an indefinitely iterated Prisoners' Dilemma *with no discounting*, since strangely he nowhere mentions discounting, and that each player's supergame payoffs are long-run averages of the constituent game payoffs. As I have already argued, these games are of little importance in the analysis of social life. They are also much simpler analytically, since they involve none of the complex trade-offs between payoffs in different time periods that are possible in supergames with discounting. In these no-discount games, (B, B) is in fact always an equilibrium and also a coordination equilibrium.

But even if (B, B), or any other strategy vector, is a coordination equilibrium, this fact does not provide each player with a 'double incentive' to conform to it. That *I* want the *other* player to conform is of no relevance to him, for we have assumed that he, like me, is a rational egoist: *my* interest in his conforming has no effect on his actions, just as my actions are unaffected by his desire that I should conform. The possibility that my interest in his actions would lead me to do something to ensure that he acts in the right way is not one that can be considered within Hardin's framework (or mine). 'My interest in your conforming means that, if there is a way to do so at little or no net cost to me, I will want to give you further incentive to conform', says Hardin,[12] but options in *this* cost-benefit comparison are not in the model to begin with and, as always, should not be wheeled in *ad hoc*.

The existence of a coordination equilibrium, then, does not give a player *two* reasons for conforming to it, and the fact that an equilibrium is a coordination equilibrium does not make it doubly likely to be the outcome. I take up the (complicated) question of which equilibrium will be the outcome in a later section.

Other mutual Cooperation equilibria

The tit-for-tat strategy is not the only strategy which, if used by both players, will sustain mutual Cooperation throughout the supergame. Any strategy which plays C on the first move and then continues to play C *if* the other player does, will do. Any two (possibly different) strategies of this sort will sustain such cooperation regardless of what the strategies require each player to do when the other player defects. Call such a strategy *conditionally cooperative*. The *conditions* for a pair of such strategies to be an equilibrium will depend on the particular strategies chosen. Consider for example the class of strategies A_k discussed by Shubik.[13] A_k, where k is a strictly positive integer, is defined as follows:

> C is chosen in the first game, and it is chosen in each subsequent game as long as the other player chooses C in the previous game; if the other Defects in any game, D is chosen for the next k games; C is then chosen no matter what the other player's last choice is; it continues to be chosen as long as the other player chooses C in the preceding game; when the other player next Defects, D is chosen for $k+1$ games; and so on; the number of games in which the other player is 'punished' for a Defection increases by one each time; and each time there is a return to C.

Denote the limiting case of A_k when $k \to \infty$ by A_{∞}: in this case, C is chosen until the other player first Defects, after which D is chosen in all succeeding constituent games.

These strategies are special cases of a class of strategies I will label $A_{k,l}$, where k is a strictly positive integer and l is a non-negative integer.

$A_{k,l}$ is the same as A_k except that the 'punishment' period (which is again of k moves duration after the other player's first Defection) is lengthened by l Defections after each succeeding Defection by the other player. When $l=0$, the punishment periods are all of the same length. When $l=1$, $A_{k,l}$ is equivalent to A_k.

The conditions for the strategy pair $(A_{k,l}, A_{k,l})$ to be an equilibrium are easily derived. If one player (i) defects unilaterally from this strategy pair to D^∞, then the other player (j) will choose C in game 1 ($t=1$), followed by D for the next k moves, then C at $t=k+2$, followed by D for the next $k+1$ moves, then C at $t=2k+l+3$, and so on. So i's total discounted payoff from the constituent games in which j plays C (and i of course plays D) is:

$$y(a_i + a_i^{k+2} + a_i^{2k+l+3} + \ldots)$$

The infinite series in parentheses is obviously convergent, since it is less than the convergent series $a_i + a_i^2 + a_i^3 + \ldots$ Call its sum $S(k, l; a_i)$ or S_i for short. We shall not need to find S_i in closed form.

Player i's discounted payoff from all the remaining moves (in which both players choose D) is then $w[a_i/(1-a_i) - S_i]$. Hence i's total discounted payoff from the supergame is:

$$(y-w)S_i + wa_i/(1-a_i)$$

Player i does not, therefore, gain by defecting to D^∞ from $(A_{k,l}, A_{k,l})$ if and only if this sum is not greater than the payoff from mutual Cooperation throughout the supergame, which is $xa_i/(1-a_i)$. This condition, on rearranging, is:

$$\left(\frac{1-a_i}{a_i}\right) S_i \leqslant \frac{x-w}{y-w} \tag{3.3}$$

Obviously, if mutual defection to D^∞ from $(A_{k,l}, A_{k,l})$ does not pay, then defection to D^∞ from (B, B) will not pay – since the former, unlike the latter, benefits from the other player's periodical return to playing C. So if condition (3.3) is satisfied, condition (3.1) should be satisfied too. This is the case, since $S_i \geqslant a_i$ regardless of the values of k and l. Note that as $k \to \infty$ (and hence the strategy $A_{k,l}$ becomes A_∞), $S_i \to a_i$, so that as $k \to \infty$ condition (3.3) becomes condition (3.1).

If player i defects unilaterally from $(A_{k,l}, A_{k,l})$ to B', the sequence of moves is:

```
 i (B'):     DCD . . . DDCD . . . DCD . . .
 j (A_k,l):  CDD . . . DCDD . . . CDD . . .
                        ↑          ↑
   t = 123 . . . . k+2 . . . . 2k+l+3 . . . .
```

Comparing this sequence of moves with that of D^∞ against $A_{k,l}$ considered above, it is clear that player i's payoff gain from moving to B' is less than his payoff gain from moving to D^∞. Hence if (3.3) is satisfied then $(A_{k,l}, A_{k,l})$ is also stable against unilateral defections to B'. And, more generally, against a player (j) who sticks to $A_{k,l}$, any switch by player i from $A_{k,l}$ to a strategy which includes C-moves during the punishment period (throughout which, remember, the other player chooses D *regardless* of i's moves, apart of course from the Defection by i which triggers the punishment) could do no better than a strategy which plays D throughout the punishment period, but is otherwise the same. The only strategy which might then improve on D^∞, when played against $A_{k,l}$, is one which plays C in the game in which j returns to playing C at the end of each punishment period. But if a strategy must play C at that point in order to be a better reply to $A_{k,l}$ than D^∞, then it must play C at the first move. Hence, against $A_{k,l}$, no strategy can do better than the better of D^∞ and any conditionally cooperative strategy. Thus, *condition* (3.3), *for both players, is a necessary and sufficient condition for* $(A_{k,l}, A_{k,l})$ *to be an equilibrium.*

As the initial 'punishment' period or the additional 'punishment' periods lengthen, that is, as k and l increase, so S_i decreases. It follows that, for given values of x, y, w and a_i, condition (3.3) is 'increasingly likely' to be satisfied as k and/or l increases. In other words, a longer 'punishment' period (a bigger value of k or l) will succeed in deterring a player from switching to D^∞ (and therefore from switching to any other strategy) where a shorter 'punishment' period has failed. Some economists, treating general non-cooperative supergames, have restricted their attention to the analogue of the N-person generalization of the strategy A_∞, in which eternal 'punishment' (D in every succeeding game) is triggered by a single Defection by the other player.[14] I agree with Shubik that this strategy contains an 'implausible' threat, and that the threats embedded in strategies A_k, for finite k, are more plausible.[15] But then, it seems to me, the strategy B (which Shubik does not mention) is even more plausible than any A_k.

Taking it in turns to Cooperate

There are many equilibria in the supergame besides those examined so far. It would be convenient if all the possible equilibria were (like those considered so far) either such as to result in mutual Cooperation throughout the supergame or such as to result in mutual Defection throughout. Unfortunately, this is not the case. One which does not fall into either category is of special interest, especially (as we shall see later) as it may be preferred by both players to mutual Cooperation throughout the supergame. This is the strategy pair in which one player uses B (tit-for-tat starting with C) and the other player uses B' (tit-for-tat starting with D). Earlier, in discussing the stability of (B, B), we saw that the pair (B, B') produces an alternation of (C, D) and (D, C) throughout the supergame. Under what conditions is it an equilibrium?

Suppose the B player is i and the B' player is j. Before either player changes strategy, i's payoff is $(z+ya_i)a_i/(1-a_i^2)$ and j's payoff is $(y+za_j)a_j/(1-a_j^2)$. It is easily verified that a change by i from B to C^∞ yields no gain if and only if

$$a_i \leqslant \frac{y-x}{x-z} \tag{3.4}$$

This is the reverse (not the negation) of condition (3.2).

A change by i from B to D^∞ or to B' produces mutual Defection throughout the supergame and yields i no gain if and only if

$$a_i \geqslant \frac{w-z}{y-w} \tag{3.5}$$

It also turns out that a change of strategy by player j from B' to B or C^∞ yields j no gain if and only if condition (3.4) holds, with j replacing i of course; and a change of strategy by j from B' to D^∞ yields j no gain if and only if condition (3.5) holds for j.

Thus conditions (3.4) and (3.5) are both necessary for (B, B') or (B', B) to be an equilibrium.

We can now show that these conditions are also jointly necessary and sufficient by applying the argument that was used earlier in proving the

sufficiency of the condition for (B, B) to be an equilibrium. The argument there showed that, against B, the best response must be to play C in every constituent game or to play D in every game or to alternate between C and D beginning with D (as would happen if B' were played). It follows that if it does not pay to switch unilaterally from B' to C^∞ or D^∞, when the other player is using B, then it does not pay to switch to any other strategy (including, for example, any strategy in the class $A_{k,l}$). A strictly *analogous* argument establishes that, against B', the best response must be to play C in every constituent game or to play D in every game or to alternate between C and D beginning with C. And from this it follows that if it does not pay to switch unilaterally from B to C^∞ or D^∞ or B', when the other player is using B', then it does not pay to switch to any other strategy.

Thus, *conditions* (3.4) *and* (3.5), *each holding for both players, are necessary and sufficient conditions for* (B, B') *or* (B', B) *to be an equilibrium.*

Putting the two conditions together, the necessary and sufficient condition is:

$$\frac{w-z}{y-w} \leqslant a_i \leqslant \frac{y-x}{x-z}$$

It is easily checked that this can be satisfied for some but not all permissible values of x, y, z, w and a_i.

So the pattern of alternation, in which the players take it in turns to Cooperate, can be an equilibrium. Whether it will ever actually be the outcome is another matter, which I address in the next section.

Before doing so, let us note the necessary and sufficient conditions, which the reader can easily derive, for (B', B'), (B', D^∞) and (D^∞, B') to be equilibria. Each of these results in mutual Defection throughout the supergame. For (B', B') the equilibrium conditions are: the reverse (not the negation) of condition (3.5) above (for both players) together with the condition

$$a_i \leqslant \frac{w-z}{x-z} \tag{3.6}$$

for both players. For (B', D^∞) the equilibrium conditions are (3.6) and the reverse of (3.5), for $i=2$ in each case. For (D^∞, B') the conditions are again (3.6) and the reverse of (3.5) but now for $i=1$ in each case.

Table 3

	B	B'	D^∞
B	(3.1) & (3.2) for $i=1, 2$	(3.5) & rev (3.2) for $i=1, 2$	Never an equilibrium
B'	(3.5) & rev (3.2) for $i=1, 2$	(3.6) & rev (3.5) for $i=1, 2$	(3.6) & rev (3.5) for $i=2$
D^∞	Never an equilibrium	(3.6) & rev (3.5) for $i=1$	Always an equilibrium

Outcomes

We have not so far considered every possible pair of strategies; nor do I intend to try. So that, even though we have established necessary and sufficient conditions for those we have considered, the following discussion, which attempts to indicate which of these equilibria is likely to be the outcome of the supergame, is incomplete. I shall confine the discussion to strategy pairs formed from B, B' and D^∞. It is unlikely that an equilibrium which is not examined here would be the outcome, since it would be equivalent to or Pareto-dominated by at least one of those that *are* considered. Table 3 assembles the relevant conditions.

The seven possible equilibria here give rise to just three distinct patterns of choices in the supergame: mutual Cooperation throughout, which occurs in the case of (B, B); the alternation pattern or 'taking it in turns to Cooperate', which results from (B, B') and (B', B); and mutual Defection thoughout, which results from (D^∞, D^∞) and the remaining three equilibria.

We noted earlier that an equilibrium is such that, if every player expects it to be the outcome, and therefore expects all the other players to choose the strategies appropriate to this equilibrium, he has no incentive to choose other than his equilibrium strategy; so the equilibrium will be the outcome. If a game has only one equilibrium, every player would expect it to be the outcome, so it would in fact be the outcome. If, for example, (D^∞, D^∞) is the *only* equilibrium in this two-person Prisoners' Dilemma supergame (i.e., none of the conditions for any of the other strategy pairs to be equilibria are satisfied), then it will be the outcome. But if two or more equilibria occurred simultaneously, then the fact that a certain strategy pair is an equilibrium is not in itself a sufficient reason

for any player to expect it to be the outcome. But if, of two simultaneously occurring equilibria, one was preferred by both players to the other, then presumably no player would expect the second to be the outcome, so it would not be the outcome.

So it would be most convenient if, whenever several equilibria occur simultaneously, one of them was preferred by each player to all the remainder (or at least was Pareto-preferred to them, i.e., was no less preferred by either of the players and was strictly preferred by at least one of them). Then we could say that no player would expect any of the Pareto-dominated equilibria to be the outcome and it would not be the outcome. Suppose, for example, that (B, B) is the only equilibrium besides (D^∞, D^∞), which is always an equilibrium. (B, B) is of course strictly preferred by both players to (D^∞, D^∞), which nobody, therefore, would expect to be the outcome. So (B, B) will be the outcome. (The same conclusion, incidentally, would be reached if $A_{k,l}$ were added to table 3. Any or all of the four pairs formed from B and $A_{k,l}$ can be equilibria, but none of the pairs formed from $A_{k,l}$ and either B' or D can be. All four, of course, lead to the same outcome – mutual Cooperation throughout the supergame.) Unfortunately, such a straightforward relation of Pareto-dominance between coexisting equilibria does not always obtain.

Suppose, for example, that the two alternation pairs (B, B') and (B', B) are the only equilibria besides (D^∞, D^∞). *Then it follows that each of the alternation pairs is Pareto-preferred to the mutual Defection equilibrium.* For if (as required by equilibrium) the B player in either of the alternation equilibria does not prefer to defect unilaterally to D^∞ (which would result in mutual Defection throughout), then he must prefer the alternation equilibrium to (D^∞, D^∞) or be indifferent between them; and if the B' player does not prefer to defect unilaterally to D^∞ (as required by equilibrium), then he certainly strictly prefers the alternation pattern to (D^∞, D^∞), because the pattern resulting from such a defection is the same as the (D^∞, D^∞) pattern, except in the first game where he is better off (as unilateral Defector) in the former than in the latter. Thus, whenever (B, B') or (B', B) are equilibria, each is Pareto-preferred to (D^∞, D^∞). In this case neither player will expect (D^∞, D^∞) to be the outcome and it will not be the outcome. This still leaves two equilibria and between these, unfortunately, the two players have opposed preferences: player 1 prefers (B', B), in which *he* Defects first, to (B, B') in which player 2 Defects first, and player 2 has the opposite preference. So even if both players eliminate from consideration all strategies except B and B', they still face the 'coordination' problem of avoiding (B, B) and (B', B') as well as the problem posed by their conflicting preferences between the two equilibria. Within the formal framework we are using, there is no resolution of this problem. In a richer specification of the model, which could be made in any particular application, a solution would no doubt be indicated. The problem has features in common with the problem of Chicken, discussed in the last chapter, and some of the remarks made in the earlier discussion apply here also. But unlike Chicken players, *both* players here prefer either of the asymmetric equilibria to mutual Cooperation. One of the alternation patterns is therefore likely to be the outcome; but which one we cannot say.

So far, then, we have seen that there can be three distinct types of outcome to the supergame:

(i) mutual Defection throughout: this occurs when (D^∞, D^∞) is the only equilibrium;
(ii) mutual Cooperation throughout: this occurs when (B, B) is the only equilibrium besides (D^∞, D^∞);
(iii) alternation between (C, D) and (D, C): this occurs when (B, B') and (B', B) are the only equilibria besides (D^∞, D^∞).

This conclusion is not modified when other equilibria in table 3 coexist with these.

It is exceedingly unlikely that (B, B) is an equilibrium as well as (B, B') and (B', B). For then both condition (3.2) and its reverse must hold, which requires that each player's discount factor is *exactly* $(y-x)/(x-z)$. I think we can ignore this possibility; but if it did occur, then the B' player (in each of the alternation equilibria) would be indifferent between alternation and mutual Cooperation, and which of these outcomes prevailed would simply depend on the other player's preferences between them.[16]

The same is true when in addition to these three equilibria (B', B') is also an equilibrium. For then not only must condition (3.2) and its reverse both hold, but also condition (3.5) and its reverse. So we must have $a_i = (y-x)/(x-z)$ *and* $a_i = (w-z)/(y-w)$ for *both* players. But then, in any case, both players are indifferent between B and B', for both yield the same payoff no matter whether the other player chooses B or B'. An even more remote possibility is that all seven of the possible equilibria in

table 3 are simultaneously equilibria, for then conditions (3.2) and (3.5) and their reverses must hold as well as conditions (3.1) and (3.6) for both players. This is possible, but very unlikely. (E.g., set $y=3$, $x=2$, $w=1$, $z=0$. Then a_i must be exactly 0.5 for both players.)

If any or all of (B', B'), (B', D^∞) and (D^∞, B') are equilibria simultaneously with (D^∞, D^∞), then if no other strategy pairs are equilibria it does not matter which of B' and D^∞ each player chooses. Mutual Defection throughout the supergame will be the upshot in any case. If these four equilibria occur simultaneously with those in the second and third cases considered above, then the conclusions in each case are unaffected: if (B, B) is also an equilibrium then it is the outcome; and if the alternation pairs are also equilibria, then one of them is the outcome.

One thing that emerges clearly from this analysis, then, is that *if each player's discount rate is sufficiently low, the outcome will be mutual Cooperation throughout the supergame.* For if the discount factors are both greater than $(y-x)/(x-z)$, then (B, B') cannot be an equilibrium (see condition (3.4)); and if both factors are *also* greater than $(y-x)/(y-w)$, then (B, B) is an equilibrium; and if (B, B) is an equilibrium then it is the outcome.

7. Epilogue: cooperation, the state and anarchy

By his entry into any society the individual . . . offers up a portion of (his) liberty so that society will vouchsafe him the rest. Anybody who asks for an explanation is usually presented with a further saying: '*The liberty of each human being should have no limits other than that of every other.*' At first glance, this seems utterly fair, does it not? And yet this theory holds the germ of the whole theory of despotism.[1]

Bakunin, *L'Empire Knouto-Germanique*

Therefore we can only repeat what we have so often said concerning authority in general: 'To avoid a possible evil you have recourse to means which in themselves are a greater evil, and become the source of those same abuses that you wish to remedy . . .'

Kropotkin, *The Conquest of Bread*

The treatment of the problem of voluntary cooperation in the first four chapters and the political theories of Hobbes and Hume as I presented them in chapter 6 rest solely on assumptions about individuals. These assumptions embody a conception of the individual as being endowed with a *given* and *unchanging* structure of preferences. More specifically, it is assumed that each individual is characterized by a certain combination of egoism and some form of altruism, and it is further assumed that this characterization does not change with time. His preferences are treated as exogenous to what has to be explained (or justified) by the theories in question. They are independent of, and do not change in response to, his social situation. He is an example of what Marx called the 'abstract man'.

This means, in particular, that no account is taken of the effect on individual preferences of the activities of the state or of the activities of the individuals themselves. If the activities of the state may result in changes in individual preferences, then clearly it cannot be deduced from

the structure of preferences in the absence of the state that the state is desirable. More generally, if individual preferences change (not necessarily as a result of state activity), the question of the desirability (or 'preferability') of the state becomes much more complex than it is in the static theories we have been considering; and if preferences change as a result of the state itself, then it is not even clear what is *meant* by the desirability of the state.

The effects of the state on individual preferences and the ways in which preferences may change in the absence of the state are the subjects of the main section of this final chapter ('The decay of voluntary cooperation'). I shall suggest there (rather inconclusively, it has to be admitted) that the effect of the state is to exacerbate the very conditions which are claimed to provide its justification and for which it is supposed to provide a partial remedy. In two preliminary sections I shall mention – much less controversially, it seems to me – two other ways in which states create or aggravate problems of the kind they are supposed to solve and undermine conditions for alternatives to the state to be workable.

In what follows I take the state to be (amongst other things) a complex system of interacting, partially independent components (like: police, security and military forces, an executive, legislature, judiciary, administrative service, and so on), and when I speak of the effects of state action I shall be referring to the aggregate (or outcome or resultant) of the components' actions which are in turn the aggregate of the actions of the individuals who staff them.

International anarchy

If, as the liberal theory argues, a state is an effective way of solving the two fundamental collective action problems of maintaining order internally and providing defence against external enemies and competitors, then the very process of becoming politically more centralised – of building or strengthening a state – is likely to be seen as threatening by neighbouring and competitor societies, and the response is likely to be the formation or strengthening of their own states, and in particular, of course, the building up of their own 'defensive' capabilities. The structure of preferences involved in this process, which can characterize relations between societies of any sort, not merely those which are usually called nations, is likely to be that of a Prisoners' Dilemma game. Interactions of this kind may also, however, generate other collective action problems, including some representable as Chicken games.[2]

If this is so, then we could say that states, established at one level (the national level, for example) to rescue people in a ('domestic') Prisoners' Dilemma or other collective action problem, may cause a Prisoners' Dilemma or other collective action problem to emerge at another level (the international level, for example) or exacerbate an already existing one.

Hobbes himself noted that 'Sovereigns', who alone can save people from the state of (domestic) 'War', are themselves in a 'state of nature', without a 'common power to keep them all in awe':

> But though there had never been any time, wherein particular men were in a condition of warre one against another; yet in all times, Kings, and Persons of Sovereigne authority, because of their Independency, are in continuall jealousies, and in the state and posture of Gladiators; having their weapons pointing, and their eyes fixed upon one another; that is, their Forts, Garrisons, and Guns upon the Frontiers of their Kingdoms; and continuall Spyes upon their neighbours; which is a posture of War. (*Lev* 98)

Nevertheless, neither Hobbes nor Hume applied to the international 'state of nature' the analysis which they made of the domestic one. But there is no reason in principle why such an application should not be made. Many people have of course done just this, arguing that a supranational state is necessary if international collective action problems, including that of the maintenance of international peace, are to be solved. And contrariwise, the possibility of conditional cooperation amongst states in the absence of such a supranational state has been taken more seriously in the last few years.[3]

The destruction of community

Hume argues that in large societies life without government is appalling, but that in small societies this need not be the case. Therefore, he says, people in a large society need, and will in fact establish, a government. When the argument is put this way, however, a radically different conclusion suggests itself: that large societies should be (or will be) disaggregated into smaller societies, and the enlargement of societies and

the destruction of small ones should be (or will be) resisted. This conclusion does not follow logically from Hume's premises any more than does his own conclusion. Given these premises (or those of Hobbes), the most that we can assert in this connection is that the larger the society, the less likely it is that there will be voluntary cooperation in the provision of public goods and in the solution of other collective action problems, principally because of the increased difficulty of conditional cooperation. If the relations between the members of a smaller group are those characteristic of community, then the usual range of positive and negative sanctions, including informal social sanctions, that are most effective in small communities, can also help to maintain cooperation in the absence of the state (though it should not then be called 'voluntary'), both directly and (like the state in Hobbes's account) indirectly through bolstering conditional cooperation.

In view of this, it is perhaps ironical that the state should be presented as the saviour of people caught in the Prisoners' Dilemmas (and other collective action problems) of a large society; for historically the state has undoubtedly played a large part in providing the conditions in which societies could grow and indeed in systematically *building* large societies and destroying small communities. The state has in this way acted so as to make itself even more necessary.

Of course, states were not alone in causing the decline of community and it is difficult to disentangle their contributions from those of other causes such as the expansion of industrial capitalism; but that the state had an important independent effect there can be no doubt.

I am not thinking so much of the very origin of the long process of state formation, when the normal process of fissioning that is characteristic of stateless societies is inhibited. Such fissioning, whereby a part of a community breaks away and establishes a replica community elsewhere, ensures that the society continues to be composed of small communities. When this is no longer possible, communities must grow in size or become joined to others. This is part of the process that leads to the *emergence* of a state. But what I have more in mind is the 'self-building' of states through the intentional destruction or absorption or weakening of (small) communities and the concomitant construction or extension or strengthening of nations or other larger societies, which can only be communities in a much weaker sense.[4] This is as true of the growth of the earliest states and of the modern European states as it is of many nations made independent since the Second World War, where the new states have often quite consciously set about weakening loyalty to ethnic and other groups within the proto-nation in order to build a single 'national solidarity'.[5]

The state, then, has in this way tended to exacerbate the conditions which are claimed (in the liberal theory) to provide its justification and for which it is supposed to be the remedy. It has undermined the conditions which make the principal alternative to it workable and in this way has made itself more desirable.

The decay of voluntary cooperation

The arguments for the necessity of the state which I am criticizing in this book are founded on the supposed inability of individuals to cooperate voluntarily to provide themselves with public goods, and especially, in the theories of Hobbes and Hume, with security of person and property. The intervention of the state is necessary, according to these arguments, in order to secure for the people a Pareto-optimal provision of public goods, or at least to ensure that *some* provision is made of the most important public goods.

In this section I suggest that the more the state intervenes in such situations, the more 'necessary' (on this view) it becomes, because positive altruism and voluntary cooperative behaviour *atrophy* in the presence of the state and *grow* in its absence. Thus, again, the state exacerbates the conditions which are supposed to make it necessary. We might say that the state is like an addictive drug: the more of it we have, the more we 'need' it and the more we come to 'depend' on it.

Men who live for long under government and its bureaucracy, courts and police, come to rely upon them. They find it easier (and in some cases are legally bound) to use the state for the settlement of their disputes and for the provision of public goods, instead of arranging these things for themselves, even where the disputes, and the publics for which the goods are to be provided, are quite local. In this way, the state *mediates* between individuals; they come to deal with each other through the courts, through the tax collector and the bureaucracies which spend the taxes. In the presence of a strong state, the individual may cease to care for, or even think about, those in his community who need help; he may cease to have any desire to make a direct contribution to the resolution of local problems, whether or not he is affected by them; he may come to feel that his responsibility to society has been discharged as soon as he has paid his taxes (which are taken coercively from him by the state), for these taxes will be used by the state to care for the old, sick and unemployed, to keep his streets clean, to maintain order, to provide and maintain schools, libraries, parks, and so on. The state releases the individual from the responsibility or need to cooperate with others directly; it guarantees him a secure environment in which he may safely pursue his private goals, unhampered by all those collective concerns which it is supposed to take care of itself. This is a part of what Marx meant when he wrote (in 'On the Jewish Question') of state-enforced security as 'the assurance of egoism'.

The effects of government on altruism and voluntary cooperation can be seen as part of the general process of the destruction of small societies by the state which was described earlier. The state, as we have seen, weakens local communities in favour of the larger national society. In doing so, it relieves individuals of the necessity to cooperate voluntarily amongst themselves on a local basis, making them more dependent upon the state. The result is that altruism and cooperative behaviour gradually decay. The state is thereby strengthened and made more effective in its work of weakening the local community. Kropotkin has described this process in his *Mutual Aid*. All over Europe, in a period of three centuries beginning in the late fifteenth century, states or proto-states 'systematically weeded out' from village and city all the 'mutual-aid institutions', and the result, says Kropotkin, was that

> The State alone . . . must take care of matters of general interest, while the subjects must represent loose aggregations of individuals, connected by no particular bonds, bound to appeal to the Government each time that they feel a common need.
>
> The absorption of all social functions by the State necessarily favoured the development of an unbridled, narrowminded individualism. In proportion as the obligations towards the State grew in numbers the citizens were evidently relieved from their obligations towards each other.[6]

Under the state, there is no *practice* of cooperation and no growth of a sense of the interdependence on which cooperation depends; there are fewer opportunities for the spontaneous expression of direct altruism and there are therefore fewer altruistic acts to be observed, with the result that there is no growth of the feeling of assurance that others around one are altruistic or at least willing to behave cooperatively – an assurance that one will not be let down if one tries unilaterally to cooperate.

A part of this argument has recently been made by Richard Sennett. Sennett's interest is in reversing the trend towards 'purified' urban and suburban communities through the creation of cities in which people would learn to cope with diversity and 'disorder' through the necessity of having to deal with each other directly rather than relying on the police and courts and bureaucracies. The problem, he says, is 'how to plug people into each others' lives without making everyone feel the same'. This will not be achieved by merely devolving the city government's power onto local groups:

> Really decentralized power, so that the individual has to deal with those around him, in a milieu of diversity, involves a change in the essence of communal control, that is, in the refusal to regulate conflict. For example, police control of much civil disorder ought to be sharply curbed; the responsibility for making peace in neighbourhood affairs ought to fall to the people involved. Because men are now so innocent and unskilled in the expression of conflict, they can only view these disorders as spiralling into violence. Until they learn through experience that the handling of conflict is something that cannot be passed on to the police, this polarization and escalation of conflict into violence will be the only end they can frame for themselves.[7]

In his remarkable study of blood donorship, *The Gift Relationship*, Richard Titmuss has given us an example of how altruism *generates* altruism – of how a man is more likely to be altruistic if he experiences or observes the altruism of others or if he is aware that the community depends (for the provision of some public good) on altruistic acts.[8] The availability of blood for transfusion is of course a public good. In England and Wales, all donations are purely voluntary (with the partial exception of a very small amount collected under pressure from prison inmates). In the United States, only 9 per cent of donations were purely voluntary in 1967 (and the percentage was falling). Of the rest, most are paid for or are given 'contractually' (to replace blood received instead of paying for it, or as a 'premium' in a family blood insurance scheme). As Titmuss recognizes, even the donors he calls 'voluntary' (those who do

not receive payment, do not give contractually, and are not threatened directly with tangible sanctions or promised tangible rewards) must have 'some sense of obligation, approval and interest'. Nevertheless, the voluntary donation of blood does seem to approximate as closely as is perhaps possible to the ideal of pure, spontaneous altruism: for it is given impersonally and sometimes with discomfort, without expectation of gratitude, reward or reciprocation (for the recipient is usually not known to the donor), and without imposing an obligation on the recipient or anyone else; and 'there are no personal, predictable penalities for not giving; no socially enforced sanctions of remorse, shame or guilt'.[9] It is, then, an example of the kind of altruism which Hume specifically declared to be very limited or absent; it is precisely not the 'private benevolence' towards family and friends which he thought was common.

Now, if there is any truth in the general argument about the growth and decay of altruism which was put forward above, we should at least expect that the *growth* of voluntary donations should be greater in a country in which non-voluntary donations are absent than in one where they are present, and even that voluntary donations should *decline* with time in a country where a very large proportion of donors were non-voluntary. This is precisely what has happened in the countries which Titmuss examines. In the developed countries the demand for blood has risen very steeply in recent years, much more steeply than the population. Yet in England and Wales, from 1948 to 1968, supply has kept pace with demand, and there have never been serious shortages. On the other hand, in the United States, in the period 1961–7 for which figures are available, supply has not kept pace with demand and there have been serious shortages; even more significantly, those blood banks which paid more than half of their suppliers collected an increasing quantity of blood in this period, while the supply to other banks *decreased*. In Japan, where the proportion of blood which is bought and sold has risen since 1951 from zero to the present 98 per cent, shortages are even more severe than in the United States.

These differences, between England and Wales on the one hand and America and Japan on the other, are consistent with the hypothesis that altruism fosters altruism (though of course they do not confirm it). Support (also inconclusive) for this explanation of the growth of blood donations in England comes from some of the responses to a question included in Titmuss's 1967 survey of blood donors in England: 'Could you say why you *first* decided to become a blood donor?'. Many people, it appears, became blood donors as a result of *experiencing* altruism: they or their friends or relatives had received transfusions. For example:

> To try and repay in some small way some unknown person whose blood helped me recover from two operations and enable me to be with my family, that's why I bring them along also as they become old enough. (Married woman, age 44, three children, farmer's wife)

> 'Some unknown person gave blood to save my wife's life. (Married man, age 43, two children, self-employed windowcleaner)

Some responses hint at an altruism resulting from an appreciation of the *dependence* of the system on altruism and of people's dependence on each other:

> You can't get blood from supermarkets and chaine stores. People themselves must come forward, sick people cant get out of bed to ask you for a pint to save thier life so I came forward in hope to help somebody who needs blood. (Married woman, aged 23, machine operator)[10]

Peter Singer, in his discussion of Titmuss's book, has drawn attention to some experiments which also support the hypothesis that altruism is encouraged by the observation of altruism.[11] He mentions an experiment in which a car with a flat tyre was parked at the side of the road with a helpless-looking woman standing beside it. Drivers who had just passed a woman in a similar plight but with a man who had stopped to change her wheel for her (this scene having of course been arranged by the experimenters) were significantly more likely to help than those who had not witnessed this altruistic behaviour.[12] Singer himself writes: 'I find it hardest to act with consideration for others when the norm in the circle of people I move in is to act egotistically. When altruism is expected of me, however, I find it much easier to be genuinely altruistic.'

The argument I have made in this section is not of course new. A similar (though not identical) argument is familiar to us from the writings of the classical liberals, and especially of John Stuart Mill. With the partial exception of Kropotkin, the only anarchist writer who makes full and explicit use of something like this argument is William Godwin. (Though Godwin is not wholly an anarchist. His case against government in the *Enquiry Concerning Political Justice* represents in most

respects a more extensive and more throughgoing application of Mill's argument than Mill himself makes.)

For Godwin, government is an evil which is necessary only as long as people behave in the way in which they have come to behave as a result of living for a long time under government. If governments were dissolved, he says 'arguments and addresses' would not at first suffice to persuade people to 'cooperate for the common advantage' and 'some degree of authority and violence would be necessary. But this necessity does not appear to arise out of the nature of man, but out of the institutions by which he has been corrupted.'[13] Later, government would not be necessary at all: there would be a transition to anarchy during which people would learn to cooperate voluntarily (or, at least, to cooperate in order to avoid the disapprobation of neighbours: 'a species of coercion' which would presumably be effective in the *small* 'parishes' of Godwin's ideal social order[14]). The growth of cooperation would in part result from the growth of benevolence. Benevolence is 'a resource which is never exhausted' but becomes stronger the more it is exercised; and if there is no opportunity for its exercise, it decays. The idea permeates much of Godwin's *Enquiry*; we see it, for example, in his criticism of punishment by imprisonment:

> Shall we be most effectually formed to justice, benevolence and prudence in our intercourse with each other, in a state of solitude? Will not our selfish and unsocial dispositions be perpetually increased? What temptation has he to think of benevolence or justice, who has no opportunity to exercise it?[15]

At the same time as Godwin wrote the *Enquiry Concerning Political Justice*, Wilhelm von Humboldt was composing *The Limits of State Action*, a book which contains many of the ideas to be found in the *Enquiry*, especially those which are of interest here.[16] Humboldt was certainly not an anarchist; but he did argue that the scope of state activity should be strictly limited to the provision of 'mutual security and protection against foreign enemies', and his case against the further interference of the state rested on arguments similar to Godwin's and more fundamentally on the axiom (on which Mill's *On Liberty* was also to be based) that '. . . the chief point to be kept in view by the State is the development of the powers of its citizens in their full individuality.'[17]

By *security*, Humboldt meant 'the assurance of legal freedom':

freedom, that is, to enjoy one's legal rights of person and property undisturbed by the encroachments of others.[18] The state must therefore investigate and settle disputes about such encroachments and punish transgressions of its laws, since these threaten security.[19] Humboldt never considers the possibility that disputes could be settled and crimes punished directly by the people themselves without the help of the state. Indeed, his only argument in support of the thesis that security must be provided by the state is that 'it is a condition which man is wholly unable to realize by his own individual efforts.[20] Yet, if this is true of security, why is it not also true of other public goods (and perhaps some other goods too)? A case can of course be made for the special status of security. One can argue, with Hobbes, that it is fundamental, being a prerequisite to the attainment of other goods. Humboldt does in fact take this line: 'Now, without security', he writes, 'it is impossible for man either to develop his powers, or to enjoy the fruits of so doing.'[21] However, in the first place, it still remains to be shown that security cannot be realized without the help of the state, and secondly, it can be argued that if the state *is* required to provide security, then for the same reasons it will be required to provide other public goods; in other words, even when they enjoy state-enforced security, citizens will not necessarily be able to obtain other things which they want without the further intervention of the state, which Humboldt expressly forbids.

Nevertheless, the arguments which Godwin uses – and Humboldt refrains from using – against *any* sort of state intervention are eloquently set out by Humboldt in his case against the intervention of the state in matters not involving security or defence. Here, in particular, is Humboldt on the effects of the state on altruism and voluntary cooperation:

> As each individual abandons himself to the solicitous aid of the State, so, and still more, he abandons to it the fate of his fellow-citizens. This weakens sympathy and renders mutual assistance inactive: or, at least, the reciprocal interchange of services and benefits will be most likely to flourish at its liveliest, where the feeling is most acute that such assistance is the only thing to rely upon.[22]

In Mill's *On Liberty* we do not encounter this argument until, at the end of the essay, he considers cases in which the objections to government interference do not turn upon 'the principle of liberty'.

These include cases, he says, in which individuals should be left to act by themselves, without the help of the state, as a means to their own development and of 'accustoming them to the comprehension of their joint interests, the management of joint concerns – habituating them to act from public or semi-public motives, and guide their conduct by aims which unite instead of isolating them.'[23] The argument appears also in the *Principles of Political Economy*, as 'one of the strongest of the reasons against the extension of government agency'.[24] Nevertheless, Mill gives to state interference a considerably wider scope than does Humboldt. In addition to the maintenance of security,[25] he allows a number of other important exceptions to his general rule of non-interference.[26]

One of these exceptions is of peculiar interest here. The exception essentially concerns 'free-rider' situations. Mill gives the example of collective action by workers to reduce their working hours. In such situations, he says, no individual will find it in his interest to cooperate voluntarily, and the more numerous are those others who cooperate the more will he gain by not cooperating; so the assistance of the state is required to 'afford to every individual a guarantee that his competitors will pursue the same course, without which he cannot safely adopt it himself'.[27] Penal laws, he goes on to say, are necessary for just this reason: 'because even an unanimous opinion that a certain line of conduct is for the general interest, does not always make it people's individual interest to adhere to that line of conduct'. This is all Mill has to say on this subject. He is merely providing an argument for an *exception* to the general rule of non-interference. He does not appear to recognize that the same argument would justify state interference in a vast class of situations. Nor, at the same time, does he appear to recognize that his general case against the interference of the state could be applied in all of these situations, including all aspects of the provision of peace and security.

Rationality

In the last chapter, I criticized Hobbes for drawing the conclusion that government is the *only* means whereby men may be coerced to Cooperate and, more fundamentally, for his relatively static treatment of the problem. I went on to note that Hume's political theory, while it also suffers from the first of these failings, to some extent remedies the second:

but although his approach is more dynamical, Hume concurs with Hobbes in concluding that Cooperation will not occur voluntarily, neglecting the possibility that the voluntary Cooperation of all individuals may occur in a dynamic game because the adoption of a conditionally Cooperative strategy is rational under certain conditions for each individual. Finally, I questioned the assumption of both Hobbes and Hume that a government-enforced state of Peace is preferred by every individual to the state of War, and in this connection I drew particular attention to the way in which government might not only impose costs on the individual but *in addition* diminish the satisfaction he derives from being in the state of Peace.

This last point refers only to a *static* effect of government – to an effect which operates in the same way at each point in time without causing cumulative changes.

Even when time is explicitly brought into the analysis in the way this is done in Hume's political theory and in chapters 3 and 4, the resulting formulation is static in a further sense, namely, that 'human nature' is taken as given and assumed to be constant. More precisely, egoism or some combination of egoism and altruism is assumed once and for all to characterize each individual; it undergoes no modification at any stage during the 'game', no matter how the players have previously behaved; and it remains unaltered upon the introduction of government and by the continued presence of government.

This assumption could be modified, and a further dynamic element injected, by allowing the combination of egoism and altruism to change over time, while still assuming that at each point of time an individual can be characterized by a utility function embodying some combination of egoism and altruism. In particular, it could now be assumed that the egoism–altruism combination changes in a way which depends on the history of the players' choices in previous games and on whether these choices were made voluntarily or as a result of the presence of state sanctions.

Modification of this sort would already take us outside the 'abstract man' framework which I mentioned at the start of this chapter, for it introduces an individual whose 'human nature' is no longer given and fixed but is partly determined by his changing social situation (including the effects on him of the state) and is something which to some extent he himself creates.

The effects of the state on individual preferences were the subject of the preceding section. The arguments put forward there were not rigorously demonstrated and no conclusive evidence was given in their support (I doubt if this is possible). But even if it is conceded only that they *may* be true, it follows that it is not at all clear what can be assumed about 'human nature' at any point in time, in particular what the structure of preferences would be in the absence of the state. The assumptions made by Hobbes and Hume were supposed to characterize human behaviour in the absence of the state; but perhaps they more accurately describe what human behaviour would be like immediately after the state has been removed from a society *whose members had for a long time lived under states*. This is surely the mental experiment which Hobbes and Hume were performing.

Although Hobbes spoke in *Leviathan* of many different characteristics of individuals, the core of his political theory makes essential use of only one of these, namely the individual's egoism or some combination of egoism and negative altruism. The same is true of Hume's political theory, except that the negative altruism of Hobbes is replaced by a severely limited positive altruism. I have tentatively suggested in this chapter that these assumptions tend to be *self-fulfilling*, in the sense that, if they were not true before the introduction of the state, which they are said to make necessary, they would in time become true as a result of the state's activity, or, if individuals already lacked sufficient positive altruism to make the state unnecessary, they would 'learn', while they lived under the care of the state, to possess even less of it.

It has often been argued that the choice of the scope and form of social institutions (such as the state) must be based on 'pessimistic' assumptions, so that they will be 'robust' against the worst possible conditions (such as a society of egoistic or even negatively altruistic individuals) in which they might be required to operate. It is assumed in such arguments that if an institution can 'work' (or work better, in some sense, than the alternatives) when everyone is, for example, egoistic, then it will certainly do the same when some or all people are positively altruistic. But if the institutions themselves affect individual preferences – affect the content of the assumptions from which their relative desirability has been deduced – then this approach is inappropriate and may be dangerously misleading. If there is any truth in the arguments I have been making – if the state is in part the cause of changes in individual preferences – then we cannot deduce from the structure of these preferences that the state is desirable. Indeed, it is not even clear in this case what it *means* to say that the state is desirable. The same objection can be made to any theory which seeks to justify or prescribe or recommend an institution, rule, practice, technology, or any set of arrangements in terms of given and fixed preferences if these are changed over time by whatever it is that is being justified.

The theory I have been criticizing and the analysis of cooperation in chapters 2–4 are founded on what has been called the *thin* theory of rationality. This is the account of rationality which is almost universally taken for granted by economists (and not just neoclassical economists). On this account, first, rationality is relative to *given* preferences (or more generally attitudes) and beliefs, which are assumed to be consistent and do not change over time, and the agent's actions are *instrumental* in achieving the given aims in the light of the given beliefs. Secondly, the agent is assumed to be a pure egoist. A somewhat less thin account would admit a measure of altruism (as was done in chapter 5). If the mix of egoism and altruism, or the propensity to act altruistically, was allowed to vary over time, then one of the components of the first characteristic of the thin account would also have been relaxed, but rationality would still be of the instrumental kind. The third crucial feature of the thin conception of rationality is that the range of incentives assumed to affect the agent is limited. As I emphasized in chapter 1, Olson's theory of collective action limits them to the increase in the public good that results from the individual's contribution, the resources he expends in making this contribution and also his contribution to organizational costs, and selective incentives which themselves are limited to the 'material' and the 'social'. Without a limitation on the range of incentives, a rational choice theory is liable to become a tautology.

Now I want to emphasize that nothing I have said in this chapter implies that the thin account of rationality cannot provide a satisfactory foundation for *any* kind of theory. In fact, my view is that the explanation of states of affairs or outcomes (however unintended these may be) in terms of individual actions, and the explanation of actions in terms of attitudes and beliefs using a thin account of rationality of some sort, are indispensable parts of any *explanatory* social theory.[28] My objection is to the use of the thin account of rationality in 'evaluative' theories, such as the liberal (or, one might say, the neoclassical) justification of the state.

So it is not my view that the 'thin' theory of collective action, of which a theory of conditional cooperation such as that developed in chapters 3 and 4 above would be a part, is an unrealistic, inapplicable theory because it rests on a thin conception of rationality. (I do nevertheless believe that the thin theory has much more explanatory power in certain sorts of situations than in others. I have tried elsewhere to characterize these situations – as well as to assess the prospects of founding explanatory theories on alternative conceptions of rationality – and I will not repeat the arguments here.)[29]

Nor do the arguments I have made in this chapter require me to abandon rational choice explanation – or methodological individualism more generally – and embrace some version of structuralism instead. The fact that individual actions, preferences and beliefs are caused – by states, for example, or by any sort of structure – does not make them explanatorily irrelevant. Just as individual actions, attitudes and beliefs are in part the products of and must be partly explained by, amongst other things, structures, so also are structures – or collective action or the origin and evolution of states – in part the products of and must be partly explained by individual actions.[30]

Annex: the theory of metagames

I am aware of only one attempt to 'rationalize' Cooperation in the *one-shot* Prisoners' Dilemma game. This is the theory of metagames proposed by Nigel Howard in his *Paradoxes of Rationality.*[1] He believes the theory to be predictive: Cooperation in the Prisoners' Dilemma is 'rational' if a player reasons in a certain way, and this mode of reasoning is claimed to be characteristic of real persons.

If Cooperation is 'rational' in the ordinary game, then it should also be 'rational' in the supergame. Our efforts in chapters 3 and 4 were clearly unnecessary if Howard's argument is valid. Anatol Rapoport believes that it is. In an enthusiastic article, he has stated that Howard's theory has 'resolved' the 'paradox' of the Prisoners' Dilemma, reconciling individual and collective rationality.[2]

In this part of the annex, I state why I believe that Howard and Rapoport are mistaken. The relevant part of Howard's argument as it applies to the Prisoners' Dilemma is first briefly presented with reference to the two-person, two-strategy case which we considered in chapter 3.

Consider the game with the following payoff matrix:

	C	D
C	x, x	z, y
D	y, z	w, w

where $y > x > w > z$. Call this now the *basic game.*

Suppose now that player 2's choices are not between the *basic strategies* C and D, but between the *conditional strategies* (Howard calls them 'policies') consisting of all the mappings from player 1's basic strategies to his own. Let S_1/S_2 denote the conditional strategy whereby

player 2 chooses S_1 if player 1 chooses C and S_2 if he chooses D. Then 2's conditional strategies are:

C/C: to choose C regardless of player 1's choice,
D/D: to choose D regardless of player 1's choice,
C/D: to choose the same strategy as player 1,
D/C: to choose the opposite of player 1's strategy.

If player 2's choices can in fact be made dependent upon player 1's choices in this way, then it is as if the two are playing in a game whose payoff matrix is:

	C/C	D/D	C/D	D/C
C	x, x	z, y	x, x	z, y
D	y, z	$\boxed{w, w}$	w, w	y, z

This is called the 2-*metagame.* Its only equilibrium is (D, D/D), corresponding to the only equilibrium (D, D) in the basic game.

Suppose next that player 1's choices are not between the basic strategies C and D but are conditional upon the conditional strategies of player 2 in the 2-metagame. Let $S_1/S_2/S_3/S_4$ denote the conditional strategy whereby player 1 chooses S_1 if player 2 chooses C/C, S_2 if he chooses D/D, S_3 if he chooses C/D, and S_4 if he chooses D/C. If the players' choices can in fact be made interdependent in this way, then it is as if they are playing a game whose payoff matrix is that shown in table 4.

This game is called the 12-*metagame.* It has three equilibria, which are marked in the payoff matrix; but if the two players were indeed playing in this game, they would not expect the uncooperative equilibrium ($D/D/D/D$, D/D) to occur, for each of them strictly prefers either of the other two equilibria. Both of these two other equilibria are outcomes of a single strategy of player 2, and since $D/D/C/D$ weakly dominates $C/D/C/D$ for player 1, both players should expect ($D/D/C/D$, C/D) to be the outcome. It is therefore the outcome. ($D/D/C/D$, C/D) corresponds to (C, C) in the basic game. In this way, according to Howard, mutual cooperation is rationalized even in the one-shot game.

A similar outcome occurs in the '21-metagame', where player 1's strategies are conditional upon the choices of player 2, which are in turn conditional upon the basic strategies of player 1. That is to say, the outcome is (C/D, $D/D/C/D$), corresponding to (C, C) in the basic game.

Table 4. *Payoff matrix for the 12-metagame*

	C/C	*D/D*	*C/D*	*D/C*
C/C/C/C	*x, x*	*z, y*	*x, x*	*z, y*
D/D/D/D	*y, z*	*w, w*	*w, w*	*y, z*
D/D/D/C	*y, z*	*w, w*	*w, w*	*z, y*
D/D/C/D	*y, z*	*w, w*	*x, x*	*y, z*
D/D/C/C	*y, z*	*w, w*	*x, x*	*z, y*
D/C/D/D	*y, z*	*z, y*	*w, w*	*y, z*
D/C/D/C	*y, z*	*z, y*	*w, w*	*z, y*
D/C/C/D	*y, z*	*z, y*	*x, x*	*y, z*
D/C/C/C	*y, z*	*z, y*	*x, x*	*z, y*
C/D/D/D	*x, x*	*w, w*	*w, w*	*y, z*
C/D/D/C	*x, x*	*w, w*	*w, w*	*z, y*
C/D/C/D	*x, x*	*w, w*	*x, x*	*y, z*
C/D/C/C	*x, x*	*w, w*	*x, x*	*z, y*
C/C/D/D	*x, x*	*z, y*	*w, w*	*y, z*
C/C/D/C	*x, x*	*z, y*	*w, w*	*z, y*
C/C/C/D	*x, x*	*z, y*	*x, x*	*y, z*

Conditional strategies of a higher order could be considered. Thus player 2's strategies could be conditional upon those of player 1 in the 12-metagame, whose payoff matrix is exhibited in table 4. (The resulting game is called the '212-metagame'.) However, neither this nor any higher order metagame would yield new equilibria, for Howard shows that all equilibria corresponding to distinct outcomes in the basic game are revealed in the n^{th}-order metagames in which each of the n players is 'named' once and only once – the 12-metagame and the 21-metagame in this two-person Prisoners' Dilemma instance.

I have two comments to make on this theory of metagames.

1. The first is for me decisive in rejecting the theory as an explanation of behaviour in the one-shot Prisoners' Dilemma in which, as I have assumed, binding agreements are not possible. In this game, the players choose their strategies *independently*; they are in effect chosen simultaneously, with no knowledge of the other's strategy. And no matter how much they may indulge in 'metagame reasoning' they must in fact ultimately choose one of their *basic* strategies.

In metagame theory, on the other hand, the player's strategies are required to be interdependent, even in this *one-shot* Prisoner's Dilemma game.

In the ordinary game, strategies could be made interdependent by use of a 'referee', not in the game theorist's usual sense, but in the sense of a third party who would be notified of the players' strategies, compare them, *and* ensure that a conditional strategy is in fact made dependent upon the specified strategies of others. However, this is equivalent to the user of a conditional strategy making his choice of a basic strategy *after* the choices of those whose strategies his depends upon.

Furthermore, the referee could in general decide a unique outcome only if the conditional strategies were of the appropriate orders of 'sophistication'. The 'resolution' of the two-person Prisoners' Dilemma takes place in the 12- or 21-metagame. Each of these games is asymmetric in the sense that one player's strategies are first-order conditional, while the other's are second-order conditional. This asymmetry is of course essential to the resolution, for if both players use conditional strategies of the same order, then some conditional strategy combinations do not yield determinate outcomes (as when, for example, each player would Cooperate if and only if the other Cooperates). This asymmetry is to some extent arbitrary; or rather, it emphasizes again that one player's choices of basic strategy must in fact follow the other's.

Of course, a player may try to ensure that other players will act Cooperatively, by announcing his intention to use a conditionally Cooperative strategy, and generally by *bargaining* with them. However, such exchanges, supposing them to be possible, would not have the effect of producing mutual Cooperation, unless agreements reached in this way were binding. Such agreements are ruled out in the specification of the game. In any case, if a mechanism for enforcing agreements existed, then the players would presumably have had little difficulty in agreeing on mutual Cooperation in the first place, and there would be no need of a theory of metagames to explain this.

Howard is neither clear nor consistent about the interpretation to be placed upon strategies in metagames. He often suggests that metagame strategies are made interdependent through *actual* bargaining (as on p. 101 of *Paradoxes of Rationality* and in applications of the theory throughout the book) and that a player's choice *follows* certain other players' choices in full knowledge of them (pp. 23, 27, 54 and 61 for example). Elsewhere, however, he seems to say that the choices are not actually sequential; the players behave *as if* they were. Thus (at the first order of sophistication), a player (k, say) 'sees' the other players choosing basic strategies, which he 'correctly predicts', while he himself plays as if he were in the k-metagame, his strategies being conditional on the other players' basic strategies. Metagames of higher order are reached ('subjectively') by similar reasoning.[3]

If the players can negotiate binding agreements or if in some other way their choices are made interdependently, then they are not playing in the Prisoners' Dilemma game which I have been discussing in this book. Yet Howard clearly assumes that they are. Part of his case for the need for a theory such as his own is based on the 'breakdown of rationality' (as this concept is used in conventional game theory) which is indicated, according to Howard, by the standard analysis of the Prisoners' Dilemma one-shot game.

The conclusions of the standard analysis of this game may be distressing; but they are unaffected by a consideration of metagames.

2. My second comment is that, if bargaining or any other dynamic process is indeed the object of study, then the one-shot game (with or without its metagames) is in any case an inappropriate model. In bargaining, there are *sequences* of choices; there are bluffs, threats and promises; there is learning and adaptation of expectations; the value of an outcome is discounted with future time; and so on. These things are not explicitly taken into account in the theory of metagames.

Notes

1. Introduction: the problem of collective action

1 This is a caricature of Hobbes's argument. In chapter 6, I give a more detailed account, making use of ideas developed in chapters 3–5.

2 Both of these are true of William J. Baumol's *Welfare Economics and the Theory of the State*, second edition (London: G. Bell, 1965). Much of this book is devoted to the failure of individuals to provide themselves voluntarily with public goods, but I think it is fair to say that 'the Theory of the State' is missing. He is careful to say that, before it is concluded that state action to ensure the supply of public goods is justified, all the *costs* of state action must also be taken into account (p. 22 in the introduction added to the second edition); nevertheless there is a *presumption* that *only* the state could ensure this supply.

3 Two examples are William Ophuls, 'Leviathan or oblivion?', in Herman E. Daly (ed.), *Toward a Steady-State Economy* (San Francisco: W. H. Freeman, 1973), and Robert L. Heilbroner, 'The human prospect', *The New York Review of Books*, 24 January 1974.

4 An approximate example is *A Blueprint for Survival*, by the editors of *The Ecologist* (Harmondsworth, Middlesex: Penguin Books, 1972; originally published as Vol. 2, No. 1 of *The Ecologist*, 1972). Their goal is not wholly anarchist, but it does include 'decentralisation of polity and economy at all levels, and the formation of communities small enough to be reasonably self-supporting and self-regulating'. For an anarchist's account of the necessity of anarchist society on ecological grounds, see Murray Bookchin, 'Ecology and Revolutionary Thought', in *Post-Scarcity Anarchism* (Berkeley, California: The Ramparts Press, 1971).

5 See, for example, Anthony Crosland, *A Social Democratic Britain* (Fabian Tract no. 404, London, 1971), and Jeremy Bray, *The Politics of the Environment* (Fabian Tract no. 412, London, 1972).

6 Garrett Hardin, 'The tragedy of the commons', *Science*, 162 (13 December 1968), 1243–8.

7 For a brief account of the overexploitation of whales and various species of fish, see Paul R. Ehrlich and Anne H. Ehrlich, *Population, Resources, Environment*, second edition (San Francisco: W. H. Freeman, 1972), pp.

125–34. See also Frances T. Christy and Anthony Scott, *The Common Wealth in Ocean Fisheries* (Baltimore: Johns Hopkins Press, 1965).

8 The word 'consumption' should perhaps be used only in connection with private goods, where it has a clear meaning. To speak of 'consuming' national defence, wilderness and radio broadcasts is somewhat strained, but for want of a suitable word to cover a variety of applications, I follow the custom of the economists and retain the word. In many cases, 'consume' means 'use'. Cf. Jean-Claude Milleron, 'Theory of value with public goods: a survey article', *Journal of Economic Theory*, 5 (1972), 419–77, at pp. 422–3.

9 This follows Samuelson's most recent usage (though I have added the requirement that a public good be also non-excludable). Samuelson had defined a *public good* as one which was consumed *equally* by every individual, so that $x^1 = x^2 = \ldots = x$, where x^i is the i^{th} individual's consumption of the good and x is the total amount available; and he defined a *private good* as one which could be divided amongst individuals so that $x^1 + x^2 + \ldots = x$. See Paul A. Samuelson, 'The pure theory of public expenditure', *Review of Economics and Statistics*, 36 (1954), 387–9. In his 1955 paper, he admitted that these were two pure, polar cases; and most recently he has abandoned these two poles in favour of a 'knife-edge pole' of the pure private good and 'all the rest of the world in the public good domain'. Samuelson, 'Diagrammatic exposition of a theory of public expenditure', *Review of Economics and Statistics*, 37 (1955), 350–6; and 'Pure theory of public expenditure and taxation', in J. Margolis and H. Guitton (eds), *Public Economics* (London: Macmillan, 1969).

10 Cf. William Loehr and Todd Sandler (eds), *Public Goods and Public Policy* (Beverly Hills: Sage, 1978), p. 2 and ch. 6.

11 For a fuller discussion of social order as a public good, see my *Community, Anarchy and Liberty* (Cambridge: Cambridge University Press, 1982), sections 2.1 and 2.3.

12 Mancur Olson, *The Logic of Collective Action* (Cambridge, Mass.: Harvard University Press, 1965), p. 36.

13 Olson, *The Logic*, p. 48.

14 Cf. *The Logic*, p. 50, note 70.

15 Russell Hardin, *Collective Action* (Baltimore: The Johns Hopkins Press for Resources for the Future, 1982), pp. 41–2.

16 Including Olson himself, as we shall see when we come to discuss altruism in chapter 5.

17 Hardin, *Collective Action*, p. 44.

18 This qualifies the very useful treatment of this issue in *Collective Action*, ch. 3.

19 Olson, *The Logic*, p. 29, note 46.

20 *The Logic*, p. 132.

21 *The Logic*, p. 61, note 17. But see also p. 160, note 91.

22 On these non-instrumental motivations, see my 'Rationality and revolutionary collective action', in Michael Taylor (ed.), *Rationality and Revolution* (Cambridge: Cambridge University Press, 1987).

23 The story about two prisoners, which gave the game its name, can be found in R. Duncan Luce and Howard Raiffa, *Games and Decisions* (New York: John Wiley, 1957), p. 95.

24 Russell Hardin, 'Collective action as an agreeable n-Prisoners' Dilemma', *Behavioral Science*, 16 (1971), 472–81.

25 Jon Elster, 'Rationality, morality, and collective action', *Ethics*, 96 (1985), 136–55. The weak definition, identifying collective action problems with the Prisoners' Dilemma, is adopted by Elster in 'Weakness of will and the free-rider problem', *Economics and Philosophy*, 1 (1985), 231–65 – but then again he admits that 'it does not . . . cover all the cases that intuitively we think of as collective action problems'.

26 Jon Elster, 'Some conceptual problems in political theory', in Brian Barry (ed.), *Power and Political Theory* (London: Wiley, 1976), at pp. 248–9.

27 Colin Clark, 'The economics of overexploitation', *Science*, 181 (17 August 1973), 630–4.

28 Taylor, *Community, Anarchy and Liberty.*

29 The two points in this paragraph where made by Brian Barry in *Sociologists, Economists and Democracy* (London: Collier-Macmillan, 1970) at pp. 27–39.

30 Olson, *The Logic*, Appendix added in 1971, p. 177.

31 Samuel L. Popkin, *The Rational Peasant: The Political Economy of Rural Society in Vietnam* (Berkeley: University of California Press, 1979), especially ch. 3.

32 Robert McC. Netting, *Balancing on an Alp: Ecological Change in a Swiss Mountain Community* (Cambridge: Cambridge University Press, 1981), especially ch. 3.

33 Lester Brown and Edward Wolf, *Soil Erosion: Quiet Crisis in the World Economy* (Washington, D.C.: Worldwatch Institute, 1984). According to this report, U.S. farms are losing topsoil at the rate of 1.7 billion tonnes a year. *The New York Times* (10 December 1985) reports that the U.S. Congress looks set to vote to pay farmers to stop farming up to 40 million acres of the worst affected land.

34 See, for example, Michael H. Glantz (ed.), *Desertification: Environmental Degradation In And Around Arid Lands* (Boulder, Colorado: Westview Press, 1977).

35 The following comments, which are critical of the property rights school's treatment of the 'tragedy of the commons', do not imply a wholesale rejection on my part of the property rights approach.

36 A. A. Alchian and Harold Demsetz, 'The property rights paradigm', *Journal of Economic History*, 33 (1973), 16–27.

37 See S. V. Ciriacy-Wantrup and Richard C. Bishop, '"Common property" as a concept in natural resources policy', *Natural Resources Journal*, 15 (1975), 713–27.

38 See, for example, Harold Demsetz, 'Toward a theory of property rights', *American Economic Review* (Papers and Proceedings), 57 (1967), 347–59.

39 Carl J. Dahlman, *The Open Field System and Beyond* (Cambridge: Cambridge University Press, 1980).

40 See, for example, Eirik G. Furobotn and Svetozar Pejovich, 'Property rights

and economic theory: a survey of recent literature', *Journal of Economic Literature*, 10 (1972), 1137–62.

41 Edna Ullman-Margalit, *The Emergence of Norms* (Oxford: Clarendon Press, 1977). A 'generalized PD-structured situation . . . is one in which the dilemma faced by the . . . participants is recurrent, or even continuous' (p. 24); but Ullman-Margalit gives no analysis of iterated games or takes any account of their distinctive problems (so, amongst other things, does not see that cooperation in these situations can occur *without* norms enforced by sanctions). Incidentally, very little of this book actually deals with the emergence of norms; it is mainly taken up with generally informal discussion of some very simple games.

42 *The Emergence of Norms*, pp. 22 and 28; my emphasis.

2. The Prisoner's Dilemma, Chicken and other games in the provision of public goods

1 This chapter draws on Michael Taylor and Hugh Ward, 'Chickens, whales, and lumpy goods: alternative models of public goods provision', *Political Studies*, 30 (1982), 350–70.

2 Russell Hardin, *Collective Action*, p. 25.

3 Russell Hardin, 'Collective action as an agreeable n-Prisoners' Dilemma', *Behavioral Science*, 16 (1971), 472–81; and again, virtually unchanged, in *Collective Action*, ch. 2.

4 Whether or not this is true of the Cournot analysis, to which one brief section is devoted, is not very important, since the Cournot approach is of little use anyway. In my view, what is involved is only a sort of pseudo-dynamics; no actual *process* is described.

5 See Dennis C. Mueller, *Public Choice* (Cambridge: Cambridge University Press, 1979), ch. 2.

6 An argument to this effect is made in Taylor and Ward, 'Chickens, whales and lumpy goods'.

7 c and b are here assumed to be independent of N. This is a reasonable assumption in many cases, including the voting one discussed earlier, but not in all cases.

8 This analysis is based on that given in Taylor and Ward, 'Chickens, whales, and lumpy goods'. It can also be found in Amnon Rapoport, 'Provision of public goods and the MCS paradigm', *American Political Science Review*, 79 (1985), 148–55. Rapoport also considers 'heterogeneous' cases where player i does not take the other players to be equally likely to Cooperate.

9 Compare Rapoport, 'Provision of public goods', pp. 150–1.

10 For further details, see Taylor and Ward, 'Chickens, whales, and lumpy goods', pp. 368–70.

11 See Hugh Ward, 'The risks of a reputation for toughness: strategy in public goods provision problems modelled by Chicken supergames', *British Journal of Political Science*, 17 (1987).

12 My presentation here draws on James M. Buchanan, *The Demand and Supply of Public Goods* (Chicago: Rand McNally, 1968); Buchanan, 'Cooperation and conflict in public-goods interaction', *Western Economic Journal*, 5 (1967), 109–21; Gerald H. Kramer and Joseph Hertzberg, 'Formal theory', in volume 7 of *The Handbook of Political Science*, F. Greenstein and N. Polsy, eds. (Reading, Mass.: Addison-Wesley, 1975); and Taylor and Ward, 'Chickens, whales, and lumpy goods'.

13 If the public good is *inferior*, then when the Others provide an additional unit of it the individual will reduce his provision of it by more than one unit.

14 John Chamberlin, 'Provision of collective goods as a function of group size', *American Political Science Review*, 68 (1974), 707–13; Martin C. McGuire, 'Group size, group homogeneity and the aggregate provision of a pure public good under Cournot behavior', *Public Choice*, 18 (1974), 107–26.

15 Chamberlin argues that if there is perfect rivalness (i.e., the good 'exhibits the same rivalness of consumption as does a private good') but non-excludability, then total production at equilibrium necessarily *decreases* as N increases. He correctly points out that if we abandon the assumption of perfect nonrivalness, the reaction curves vary with N. But they need not vary in the particular manner he assumes. Changes in an individual's reaction curve as N varies can come about as a result of changes in the transformation function facing the individual *or* in his indifference map. This follows from the remarks made at the end of the last section. Chamberlin, like many others, conflates indivisibility and nonrivalness, but my point that the reaction curves need not vary in the way he assumes holds whether their variation as N varies is due to changes in the transformation function or the indifference map or both. The (true) statement that when the public good is not purely indivisible or there is some degree of rivalness, the group's total production may increase or decrease, is said by Chamberlin to hold only for the cases 'intermediate' between perfect nonrivalness and perfect rivalness; but here too the two patterns of variation in the reaction curves as N varies which Chamberlin considers do not exhaust the possibilities. In any case, reaction curves will be radically different from the ones he considers in some important cases, in particular in lumpy goods cases, as discussion in the text below suggests.

3. The two-person Prisoners' Dilemma supergame

1 The number r_i such that $a_i = 1/(1+r_i)$ is sometimes called the rate of time preference.

2 This has not deterred some economists and game theorists in recent years from studying finite supergames and infinite supergames with no discounting. On infinite games *without discounting*, see especially A. Rubinstein, 'Equilibrium in supergames with the overtaking criterion', *Journal of Economic Theory*, 21 (1979), 1–9; Steve Smale, 'The Prisoners' Dilemma and

dynamical systems associated to non-cooperative games', *Econometrica*, 48 (1980), 1617–34; and Robert J. Aumann, 'Survey of repeated games', pp. 11–42 in R. J. Aumann, *et al.*, *Essays in Game Theory and Mathematical Economics in Honor of Oskar Morgenstern* (Mannheim/Wien/Zurich: Bibliographisches Institut, 1981). For *finitely* repeated games, see especially the works cited in the next note. I think, however, that most economists believe that supergames of indefinite length with discounting are generally the most appropriate model.

3 This well-known result for the finitely repeated Prisoners' Dilemma no longer holds if a small amount of uncertainty is introduced into the game. If players are not quite certain about each other's motivations, options or payoffs, the backwards induction argument cannot be applied. See David M. Kreps, *et al.*, 'Rational cooperation in the finitely repeated Prisoners' Dilemma', *Journal of Economic Theory*, 27 (1982), 245–52; David M. Kreps and Robert Wilson, 'Reputation and imperfect information', *Journal of Economic Theory*, 27 (1982), 253–79; and Kreps and Wilson, 'Sequential equilibria', *Econometrica*, 50 (1982), 863–94.

4 Mixed strategies are ruled out, chiefly because they do not seem to correspond to any realistic course of action in the real world problems of public goods provision which are of interest in this book.

5 This chapter extends, in certain respects, earlier work on the two-person Prisoners' Dilemma supergame in Martin Shubik, *Strategy and Market Structure: Competition, Oligopoly, and the Theory of Games* (New York: Wiley, 1959); Shubik, 'Game theory, behavior, and the paradox of the Prisoners' Dilemma: three solutions', *Journal of Conflict Resolution*, 14 (1970), 181–93; and Michael Nicholson, *Oligopoly and Conflict* (Liverpool: Liverpool University Press, 1972).

6 Observe that the payoff matrix is *symmetric*: it remains unchanged when the players are interchanged (relabelled). Abandoning symmetry (while retaining the Prisoners' Dilemma ordering of the payoffs) would require modifications of detail (in the conditions below for strategy vectors to be equilibria, the payoffs would have to be subscripted as well as the discount factors); but the general argument would not be changed. In this book, I wish to isolate the Prisoners' Dilemma element.

7 Robert Axelrod, *The Evolution of Cooperation* (New York: Basic Books, 1984), pp. 208–9.

8 *The Evolution of Cooperation*, p. 173.

9 This last point is made by Norman Schofield, 'Anarchy, altruism and cooperation', *Social Choice and Welfare*, 2 (1985), 207–19.

10 *The Evolution of Cooperation*, p. 11 and p. 216 note 3.

11 Russell Hardin, *Collective Action*, p. 171.

12 *Collective Action*, p. 171.

13 Martin Shubik, 'Game theory, behavior, and the paradox of the Prisoner's Dilemma: three solutions', *Journal of Conflict Resolution*, 14 (1970), 181–93.

14 This strategy was introduced, I think, by Martin Shubik in *Strategy and Market Structure*, at pp. 224–5. Its analogue for any noncooperative game is studied by James W. Friedman in 'A non-cooperative equilibrium for supergames', *The Review of Economic Studies*, 38 (1971), 1–12. See also John McMillan, 'Individual incentives in the supply of public inputs', *Journal of Public Economics*, 12 (1979), 87–98.

15 Shubik, 'Game theory, behavior, and the paradox of the Prisoner's Dilemma'.

16 A parenthetical comment is appropriate here on the condition $2x > y+z$, which is stipulatively required in some accounts of the Prisoners' Dilemma, on the grounds that, if it did not hold, then alternating between (C, D) and (D, C) would be preferable to mutual Cooperation. (It is required, for example, by Anatol Rapoport and Albert C. Chammah in their pioneering book, *The Prisoner's Dilemma*, Ann Arbor: The University of Michigan Press, 1965, p. 34.) The condition does indeed rule this out in a Prisoners' Dilemma supergame without discounting (and accordingly plays an important role in models of this supergame such as the one discussed in the annex); but in the present analysis, in which players discount future payoffs, it is *not* sufficient to make either of the alternation patterns Pareto-preferred to mutual Cooperation. In fact, for the B' player to prefer mutual Cooperation throughout the supergame to (B, B') or (B', B) we require $a_i > (y-x)/(x-z)$, and for the B player to prefer it we require $a_i < (x-z)/(y-x)$. These two inequalities, then, each holding for both players, are the necessary and sufficient conditions for mutual Cooperation to be preferred by both players to either of the alternation outcomes. I have preferred not to stipulate this but instead to analyse the conditions under which alternation occurs. The condition $2x > y+z$ is nevertheless a *necessary* condition for (B, B) to be preferred to (B, B') and (B', B) by the B' player (and is therefore a necessary condition for (B, B) to be an equilibrium), since one of the necessary conditions for this is $a_i > (y-x)/(x-z)$, and since $a_i < 1$ we must have $(y-x)/(x-z) < 1$, that is, $2x > y+x$.

4. The *N*-person Prisoners' Dilemma supergame

1 This was not made clear in *Anarchy and Cooperation*.

2 A different definition of the N-person Prisoners' Dilemma is given by Thomas C. Schelling in 'Hockey helmets, concealed weapons, and daylight saving: a study of binary choices with externalities', *Journal of Conflict Resolution*, 17 (1973), 381–428. He defines a 'uniform multiperson prisoner's dilemma' as a game such that: (1) each player has just two strategies available to him and the payoffs can be characterized (in effect) by two functions $f(v)$ and $g(v)$, which are the same for every individual; (2) every player has a dominant strategy (D); (3) $f(v)$ and $g(v)$ are monotonically increasing; (4) there is a number $\kappa > 1$, such that if κ or more players choose C and the rest do not, those who choose C are

better off than if they had all chosen D, but if they number less than κ, this is not true. Schelling's (1) and (2) are also part of my definition. His (3) is a much stronger requirement than my (iii). And his (4) is stronger than my (ii). For all I require in (ii) is that the first part of Schelling's (4) holds for $\kappa = N$; and I leave open the question of whether fewer than N individuals obtain a higher payoff when they all Cooperate (and the rest do not) than when they all Defect. Schelling's definition is therefore more restrictive than mine. His requirement (4), it seems to me, partly removes the 'dilemma' in the Prisoners' Dilemma.

Other ways of defining the N-person Prisoners' Dilemma more restrictively than I define it here can be found in Henry Hamburger, 'N-person Prisoner's Dilemma', *Journal of Mathematical Sociology*, 3 (1973), 27–48.

3 If there is some symmetry between the payoff functions of different players, the number of these equilibria might be smaller; but as long as *some* remain the problem to be discussed in the text would still arise. Only exceptionally would the asymmetry be such that there is just *one* subset of players such that $(B_n/C^\infty/D^\infty)$ is an equilibrium.

4 Michael Laver, 'Political solutions to the collective action problem', *Political Studies*, 28 (1980), 195–209; and Iain McLean, 'The social contract and the Prisoner's Dilemma supergame', *Political Studies*, 29 (1981), 339–51.

5 Early indications from simple computer simulation exercises with one such model (in unpublished work by Hugh Ward) suggest that a pre-commitment 'scramble' could occur which levelled out and stabilized at the desired subgroup size.

6 See the references in notes 14 and 15 to chapter 3.

7 A *very* small group *may* be 'privileged' in Olson's sense (i.e., there is at least one individual who is willing to provide some of the public good unilaterally), in which case, as we saw in chapter 2, preferences at any point in time are not those of a Prisoners' Dilemma, and the whole argument of this chapter is inapplicable. If there are *several* such individuals, each of whom has a very strong interest in the public good, a different problem of strategic interaction arises. See the discussion in chapter 2.

8 See the brief discussion in chapter 1 and for a fuller account see my *Community, Anarchy and Liberty* (Cambridge: Cambridge University Press, 1982), ch. 2.

9 This conclusion finds some support in Michael Nicholson's work, although his analysis cannot be compared directly with the one carried out here. See *Oligopoly and Conflict* (Liverpool: Liverpool University Press, 1972), Section 3.2. See also his discussion of this type of flexibility in chapter 6.

5. Altruism and superiority

1 Olson, *The Logic of Collective Action*, p. 64.

2 Brian Barry pointed this out in *Sociologists, Economists and Democracy*, at p. 32.

3 I have made this argument in more detail in 'Rationality and revolutionary collective action'.

4 A parenthetical comment is in order to explain why I have made no use of the model of altruistic behaviour proposed by Howard Margolis in his *Selfishness, Altruism, and Rationality* (Cambridge: Cambridge University Press, 1982), which on the face of it offers a much more realistic account of altruism than the simple one used here. Certainly, I believe that Margolis's theory is the most interesting attempt to date to incorporate altruistic motivation into a model of individual choice; but unfortunately it is radically incomplete and, as far as I can see, unusable. I have set out my reasons for reaching this conclusion elsewhere (*Ethics*, 94 (1983), 150–2) and will not repeat them here. To summarize drastically, an individual on Margolis's account allocates his resources between 'selfish' and 'group' interests in such a way as to feel that he has done his 'fair share', and the rule which yields allocations answering to this is as follows: 'the larger the share of my resources I have spent unselfishly, the more weight I give to my selfish interests in allocating marginal resources. On the other hand, the larger benefit I can confer on the group compared with the benefit from spending marginal resources on myself, the more I will tend to act unselfishly' (Margolis, p. 36). So the weight the individual gives to his selfish interests is a function of the *history* of his past (altruistic and/or egoistic) behaviour. But *how* this weight varies with the individual's history is not specified. Margolis does not in fact consider in detail any *dynamic* examples and it is not at all clear how the model can be applied to dynamic games in which there is strategic interaction over time.

5 What I have called Games of Difference have been considered by James R. Emshoff in 'A computer simulation model of the Prisoner's Dilemma', *Behavioral Science*, 15 (1970), 304–17. He refers to λ_i as the 'competitiveness parameter'. Pure Difference Games have been studied by Martin Shubik, 'Games of status', *Behavioral Science*, 16 (1971), 117–29, who calls them 'difference games'. He considers also a further transformation to what he calls 'games of status', in which there are only three different payoffs: one for winning (when the payoff difference is positive), one for losing (when the difference is negative) and one for drawing.

6 Sophisticated altruism or something like it is discussed under different names by Stefan Valavanis, 'The resolution of conflict when utilities interact', *Journal of Conflict Resolution*, 2 (1958), 156–69 and Thomas C. Schelling, 'Game theory and the study of ethical systems', *Journal of Conflict Resolution*, 12 (1968), 34–44.

6. The state

1 References to *Leviathan* (abbreviated *Lev*) are to the pages of the edition by W. G. Pogson Smith (Oxford: The Clarendon Press, 1909).

2 I must thank Brian Barry for helping me to see *Leviathan* in a more 'dynamic' light.
3 Alasdair MacIntyre, *A Short History of Ethics* (London: Routledge and Kegan Paul, 1967), p. 138.
4 H. L. A. Hart, *The Concept of Law* (Oxford: The Clarendon Press, 1961), p. 193.
5 Brian Barry, 'Warrender and his critics', *Philosophy*, 48 (1968), 117–37, at p. 125.
6 On symmetry, see chapter 3, note 6.
7 C. B. Macpherson, *The Political Theory of Possessive Individualism: Hobbes to Locke* (Oxford: The Clarendon Press, 1962).
8 The citations of Hume give the page numbers of the Selby-Bigge editions: L. A. Selby-Bigge (ed.), *A Treatise of Human Nature* (Oxford: The Clarendon Press, 1888) and *Enquiries Concerning the Understanding and Concerning the Principles of Morals* (Oxford: The Clarendon Press, second edition, 1902). The *Treatise* is abbreviated to *Tr* and *Enquiry* refers to *An Enquiry Concerning the Principles of Morals.*
9 David Lewis, *Convention: A Philosophical Study* (Cambridge, Mass.: Harvard University Press, 1969), p. 42. Lewis later refines this definition by adding the condition that it is 'common knowledge' in *p* that (1), (2) and (3) obtain. He also considers *degrees* of convention. But this 'first, rough definition' will suffice for my purposes.
10 Governments are in fact very active in establishing and modifying conventions and in many cases they make laws of them and punish non-conformists. If they are pure conventions, this is not necessary. For example, driving on the 'right' side of the road is almost a pure convention, and once it is established, there is almost no need for government enforcement: very few individuals will want to drive on the 'wrong' side. Of course, a central coordinating agency may be useful in *establishing* a convention more quickly and less painfully than it would establish itself 'spontaneously'. But this is not an argument in favour of government; for such an agency need have no *power*, and it need only be *ad hoc* and temporary: there is no need, in this connection, for a single agency to take charge of all conventions, and once a convention is established, the agency in question can be disbanded.

7. Epilogue: cooperation, the state and anarchy

1 Arthur Lehning (ed.), *Michael Bakunin: Selected Writings* (London: Jonathan Cape, 1973; New York: Grove Press, 1973).
2 For introductory accounts of problems of arms races and disarmament in terms of Prisoners' Dilemma games and of other international interactions in terms of Chicken games, see Anatol Rapoport, *Strategy and Conscience* (New York: Harper and Row, 1964); Glenn H. Snyder, '"Prisoners' Dilemma" and "Chicken" models in international politics', *International Studies Quarterly*, 15 (1971), 66–103; Glenn H. Snyder and Paul Diesing, *Conflict Among Nations: Bargaining, Decision Making, and System Structure in International Crises* (Princeton, N.J.: Princeton University Press, 1977); Robert Jervis, 'Cooperation under the security dilemma', *World Politics*, 30 (1978), 167–214.

3 See, most recently, Kenneth Oye (ed.), *Cooperation Under Anarchy* (Princeton, N.J.: Princeton University Press, 1986).
4 See the brief account of community in the penultimate section of chapter 1 above.
5 For example, Rupert Emerson, writing on the new nations of Africa in a volume on Nation-Building, has this to say: 'At the extremes, tribalism can be dealt with in two fashions – either use of the tribes as the building blocks of the nation or eradication of them by a single national solidarity. It is the latter course which is more generally followed.' And William Foltz, speaking generally of the new nations in his conclusion to this volume, writes: 'The old argument over the priority of state or nation is being resolved by these countries' leaders in favour of first building the state as an instrument to bring about the nation'. See Karl W. Deutsch and William J. Foltz (eds), *Nation-Building* (New York: Atherton Press, 1963). On European states, see for example Charles Tilly, 'Reflections on the history of European state-making', in Tilly (ed.), *The Formation of National States in Western Europe* (Princeton, N.J.: Princeton University Press, 1975), especially at pp. 21–4, 37 and 71.
6 Peter Kropotkin, *Mutual Aid: A Factor of Evolution* (London: Allen Lane The Penguin Press, 1972; reprinted from the edition of 1914), p. 197.
7 Richard Sennett, *The Uses of Disorder: Personal Identity and City Life* (London: Allen Lane The Penguin Press, New York: Alfred A. Knopf, 1971). This quotation is from the Pelican edition (Harmondsworth, Middlesex: Penguin Books, 1973), pp. 132–3, by courtesy of Penguin Books Ltd and Alfred A. Knopf Inc.
8 Richard M. Titmuss, *The Gift Relationship: From Human Blood to Social Policy* (London: George Allen and Unwin, New York: Random House, 1970). References here are to the Pelican edition (Harmondsworth, Middlesex: Penguin Books, 1973), quoted by courtesy of George Allen & Unwin Ltd and Pantheon Books, a Division of Random House, Inc.
9 *The Gift Relationship*, pp. 84–5.
10 *The Gift Relationship*, pp. 256–8.
11 Peter Singer, 'Altruism and Commerce: A defense of Titmuss against Arrow', *Philosophy and Public Affairs*, 2 (1973), 312–20.
12 This experiment is reported in J. H. Bryant and M. A. Test, 'Models and helping: naturalistic studies in aiding behavior', *Journal of Personality and Social Psychology*, 6 (1967), 400–7. The best source for reports of experiments of this kind is J. Macaulay and L. Berkowitz (eds), *Altruism and Helping Behavior* (New York: Academic Press, 1970), especially the chapters of the