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Binary Games as Models of Public Goods Provision*

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Problems of public goods provision are categorized according to attributes of the good to be provided, and properties of the group of potential beneficiaries. It is argued that not all such problems are Prisoner's Dilemmas. Other games of interest include Chicken, the Volunteer's Dilemma, a variant of the Assurance Game, and several others. Which particular model is relevant in a given context depends critically on the specific characteristics of the situation under consideration.

Introduction

The purpose of this paper is threefold. First, I hope to contribute to an understanding that not all problems of public goods provision are Prisoner's Dilemmas. Second, I intend to survey some of the *existing* alternatives to the Prisoner's Dilemma-model, as well as to present some *new models* which I consider relevant to the study of this kind of problems. Finally, I try to identify the specific conditions under which each model is appropriate.

The article is organized as follows. The first section gives a brief outline of some of the limitations, as well as the possibilities, inherent in the use of binary choice n-person games, which is the central analytical tool used throughout the paper. The next provides four important distinctions which are used to categorize different types of public goods provision problems. These distinctions are (i) Whether the good in question is of an 'inclusive' of 'exclusive' nature; (ii) Whether the good can be provided in continuously divisable amounts, or only in discrete 'steps' or 'lumps'; (iii) Whether the group under consideration is large or small; and (iv) Whether or not the group is symmetrical, in the sense that all group members are of equal size and take an equal interest in the provision of the good. Having explored these distinctions, I then turn to a discussion of the various symmetric cases, and finally some asymmetrical possibilities are presented.

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theoretic models was developed – to my knowledge independently – by Thomas C. Schelling and Henry Hamburger in the 1970's (Hamburger 1979, Schelling 1978).

An obvious strength of this kind of models is their perplexing simplicity, making complex strategic situations easily comprehensible to students without extensive knowledge of mathematics. However, in some of the examples to be discussed below, such models may be criticized for being *too* simplistic. While in some cases – such as certain instances of voting – each participant faces a genuine binary choice, in others there is a continuous set of alternative strategies available to each player. The latter possibility applies, for example, when contributions to the provision of a public good can be given in the form of a freely chosen amount of money. Thus, while the models presented below typically depict the alternatives as being 'Cooperation' and 'Defection', respectively, in many real-world situations each agent may choose from a variety of *levels* of cooperation. This simplification has as a consequence that conclusions drawn from binary models are not always completely equivalent to those obtained from corresponding (and possibly more realistic) models of the same phenomenon which explicitly assumes the existence of continuous action variables. Although I shall try to point out some divergences of this kind, such comments will mainly be confined to the footnotes.

Some of the models that are discussed below have clear analogies within the realm of 2×2-games. However, it is also clear that many have not. Wherever such parallels exist, they are indicated by using the names of the 2×2-games that correspond to the n-person games that are actually considered.

Finally, a note on the way the material is presented: The aim here is to indicate the span of variety within the realm of models relevant to problems of public goods provision. The number of models, together with limited space, makes it necessary to deal with each particular model in a somewhat superficial manner. Hence, no extensive discussion of the likely outcome under various rules of the game in each model has been possible – although the matter is of course not completely ignored. The main focus of the article, it should be kept in mind, is on the categorization of different types of situations that may arise, rather than discussion of the implications of each particular situation.

Some Central Distinctions

Following Mancur Olson, a public (or collective) good is here defined as

> ... any good such that, if any person x_i in a group x_1, ..., x_i, ..., x_n consumes it, it cannot feasibly be withheld from others in that group. (Olson 1965, 14)

Thus, the defining characteristic of public goods is held to be *nonexcludability*.

The specific character of the problems inherent in providing such goods depends on at least 4 other aspects of the situation under consideration. Two are concerned with characteristics of the particular good to be provided, while the others deal with the structure of the relevant group.

The first distinction concerns the extent to which the good is characterized by *nonrivalness of consumption*. This refers to whether or not consumption of the good by one individual significantly subtracts from others' consumption of it.[1] If a public good is also characterized by nonrivalness of consumption, it is called an *inclusive* good (Olson 1965, 38). Among the standard examples of this kind of goods are the lighthouse, fresh air and national defense. If, on the other hand, the consumption of one individual significantly detracts from the amount of the good being available to others, Olson speaks about *exclusive* goods. A typical example is the extra profits being available to the firms in a particular industry, if they act in concert to restrict aggregate output. If one firm sells more at a given price, others have to sell less, so that the total benefits that can be gained from a higher price is fixed. Another example, even more easy to grasp, is the traditional pie. Suppose that for some reason, it is not feasible to exclude any member of a given group from sharing a pie once it has been provided, so that the pie is a public good for the group. Since any piece of the pie that is consumed by one person cannot be eaten by others, we have an example of a good exhibiting perfect rivalness of consumption.

The second distinction refers to whether or not the good is of a 'lumpy' nature, i.e., whether it can be provided only in some minimal amount, or is available in continuous quantities (Taylor & Ward 1982). An example of the first type of good is again the lighthouse, while national defense or clean air may be said to be continuous goods – at least unless there exists a certain threshold beneath which expenditure on weapons has no deterrence effect, or abatement is useless. The qualification should remind us that the lumpiness-distinction is one of degree, rather than a dichotomy. Thus, Taylor & Ward suggest that many environmental goods have a somewhat 'lumpy' character:

> 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. (Taylor & Ward 1982, 354).

Further examples of lumpy goods can be found with goods of the public works variety, e.g. roads, rails and bridges. In all these cases provision is only possible in more or less massive 'lumps'. In addition, electoral victory is sometimes mentioned as an example of a lumpy good, since one or two votes may sometimes be pivotal among millions (Hardin 1982, 59).

A third aspect of situations of public goods provision to be discussed here is the *size* of the relevant group. The importance of this variable has been particularly stressed by Mancur Olson (1965), who argued that public goods provision through voluntary contributions by group members is more likely in small groups (e.g. families, neighboring municipalities, a region of nation-states), than in large groups (e.g. the producers in a competitive market, the world community). According to Olson, the reason for this is the different incentives facing members of small and large groups. In small groups, each individual receives a relatively large fraction of any amount of the public good he is providing, while in large groups this fraction is correspondingly small. Since each individual has to bear the full cost of his contribution himself, it follows that it will be less likely that it pays for any individual to make a contribution, the larger the group in question.

However, as Chamberlin (1974) has shown, Olson's conclusion depends critically on the assumption that we are dealing with an exclusive good. This is due to the fact that the 'fraction-of-the-gains' reasoning has no meaning in the case of an inclusive good. In the latter case, each member of the group can consume whatever amount of the good that is provided, regardless of the number of other consumers involved. To put it another way, each and every individual's consumption equals the total amount of the good being provided. This makes much of Olson's reasoning inappropriate as far as inclusive goods are concerned, because the incentive for making 'the first' contribution (i.e. for making a contribution in the case that nobody else is expected to do so) is then unaffected by the number of individuals involved. Indeed, as far as inclusive goods are concerned, the incentive for making 'the first' contribution is the same as if there were no externalities involved at all – i.e. as if the individual were in a state of complete isolation, or the good under consideration were a pure private good.

The final distinction to be made here concerns the question of whether or not we are dealing with a group that is *symmetric,* in the sense that all members are of equal size and take an equal interest in the provision of the collective good. As Olson has pointed out, in groups with significant inequalities among members in these respects, there is '... the greatest likelihood that a collective good will be provided' (Olson 1965, 34). What is less often acknowledged, however, is that the logical grounds for this proposition – while true in both instances – differs significantly according to whether we are dealing with an inclusive or exclusive good. As we shall see in the final section, this fact calls for different game-representations in the two instances, although both models yield the same predictions with regard to substantial behavior. First, however, I shall discuss the various symmetric situations.

Symmetric Cases

Combining the first three pairwise distinctions discussed in the previous section, gives us eight categories, as shown in Fig. 1.

	Exclusive goods		Inclusive goods	
	Large groups	Small groups	Large groups	Small groups
Continuous goods	1	2	3	4
'Lumpy' goods	5	6	7	8

Fig. 1. Categories of Problems of Public Goods Provision.

Although some of the possibilities in Fig. 1 can be said to be equivalent in most respects, I have found it practical to take this categorization as my point of departure. Hence, I shall discuss the various situations according to their number in the matrix.

Continuous Goods

The *first category* is the one that most writers seem to have in mind when discussing problems of public goods provision. Since the good is exclusive, and the group is (by assumption) symmetrical, each member will get only a fraction $f = 1/n$ of whatever amount of the public good that is provided. Since the group is large (i.e. n is large), f is accordingly small. This makes it unlikely that it will ever pay for any group member to make a contribution, since all of the cost from such a contribution will have to be borne by the contributor himself, while only a fraction f of the additional gains accrues to him. And since the good is of a continuous nature, the additional gains tend to be small, in the sense that no minor contribution can ever be pivotal for the provision of a large amount of the good (which may be the case for lumpy goods).

However, if no-one makes a contribution, the public good will not be provided, leaving all group members worse off than they would have been if everyone had cooperated. The problem of providing a continuous, exclusive good in a large group is, in other words, a standard example of an n-person Prisoner's Dilemma, shown in Fig. 2.

Fig. 2. depicts the utility accruing to any member i of this type of group from choosing C (Cooperation) or D (Defection) respectively, as functions of the number of other members choosing C. This number is labeled c_i, the subscript indicating reference to player no. i. The situation where all members choose D is represented by the origin of the figure. In our case, where everyone involved has

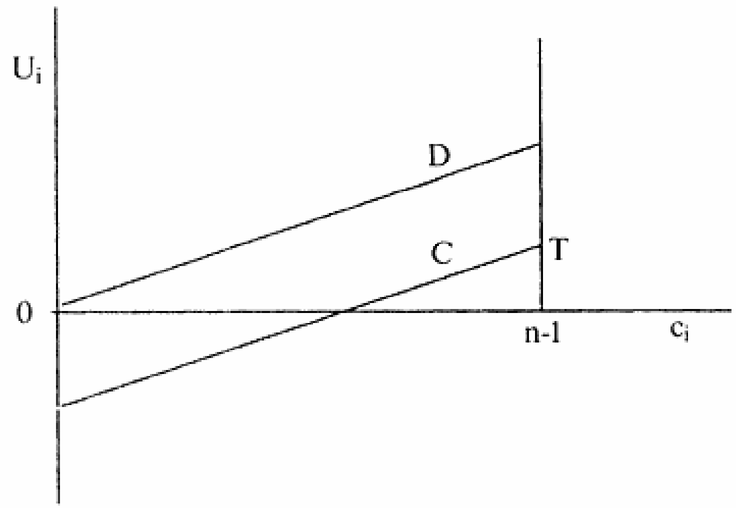

Fig. 2. The Prisoner's Dilemma.

D as a dominant strategy, the origin is also the only equilibrium and natural solution of the game. It is, however, easy to see that the outcome 'all D' is Pareto-inferior to 'all C', located at point T in Fig. 2.

The standard example of this type of situation concerns the prospects for establishing a price above the competitive level for producers in a competitive market. The good (the extra profits from a higher price) is exclusive, as already discussed above. Furthermore, it can be provided in continuously divisible amounts and the number of group members is (infinitely) large.

The *second category* is, of course, Olson's small group case. It differs from category 1 only in the number of group members. The consequences of this are easy to see: A smaller n increases the fraction $f=1/n$ of the gains that each member receives from the public good. This makes it more likely that it pays for each member to provide some of the good, at least if nobody else is expected to do so. However, given that others provide a sufficient amount of the public good, it probably pays to defect even in this case. This is because some of the good is provided anyway, and the group member under consideration may therefore find it in his interest to allocate his scarce resources for other purposes than adding further to the available amount of the public good.

This might indicate that *Chicken* is a more adequate model than the Prisoner's Dilemma in situations of category 2. An n-person version of this game is presented in Fig. 3.

In Fig. 3, it pays for each group member to cooperate if, and only if, *less* than some critical number (labeled c_i^0) of others do the same thing. Since the good is continuous, it is assumed that more contributions always increase the available amount of the good, thereby improving the situation for other group members.

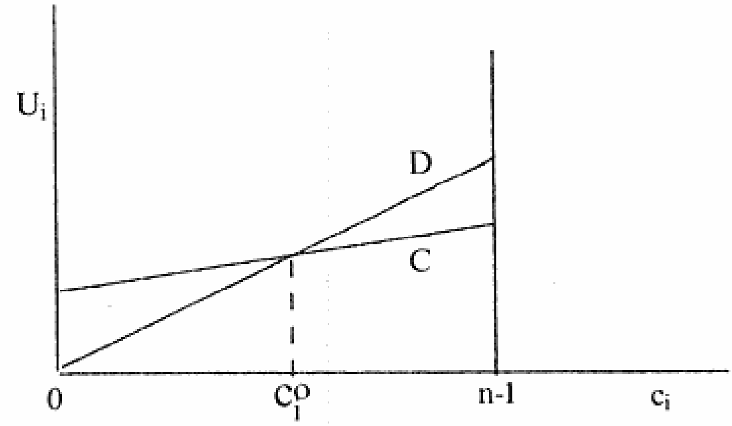

Fig. 3. Chicken.

Hence, the utility curves in Fig. 3 (as well as in Fig. 2) are always rising with increasing values of c_i.

It should be noted that the game in Fig. 3 always has multiple equilibria in the symmetric version, i.e. when all players have identical preferences (more specifically: identical c_i^o-values). However, for our purposes it suffices to say that all equilibria implies that 'about' c_i^o members of the group cooperate, while the others defect.[2] Although it is difficult to give reasons why an equilibrium should materialize here if the game is played only once, it seems safe to predict that with repeated games, the players will approach *some* equilibrium – even if it is difficult to tell which one. In this sense the outcome can be said to be determinate in *macro*, but not in *micro:* it is possible to predict *how many*, but not *which* players will choose the cooperative strategy.

If this conclusion is accepted, the Chicken-version of this situation yields predictions very similar to those reached by Olson. It is *possible* (perhaps even *likely*) that some of the collective good will be provided. However, the provision may not be optimal, since it may very well be the case that all members prefer the outcome 'all C' to all outcomes where only c_i^o members cooperate.

If the situation of producers in a competitive market fits category 1, then category 2 may be represented by the case of oligopoly. In a market with only a few producers it may pay for any one of them to limit his own output, given that others produce at full capacity. However, if others collaborate to keep prices up, it is advantageous to sell as much as possible at a profitable price. Further examples that possibly fit this category may be economic growth (Olson 1982, Rasch & Sørensen 1986), and certain cases of international fisheries (Underdal 1980).

Turning to *categories 3 and 4,* we now attend to the provision of inclusive goods. As already noted, for this type of goods the consumption of each and every group member equals the total amount being provided.[3] This means that the fraction f in such instances is equal to 1, no matter the number of individuals involved. In this sense, the incentives facing each group member to some extent resemble cases where $n = 1$, i.e. cases where the individual is completely isolated, or where the good in question is of a purely private nature.

In the case of continuous, inclusive goods, then, we can be sure that it pays for each group member to provide *some* amount of the collective good if nobody else is expected to do so, i.e. each player prefers C to D when c_i equals 0. To deny this is simply to deny that the good is worth its cost for *any* possible amount of provision, implying that we are not strictly talking about a good at all.[4]

Again, however, the incentive to make a contribution declines with increasing cooperative efforts by other group members. This is even more obvious in these cases than in category 2, because literally *all* of the good being provided by one group member can also be consumed by other members of the group. Since all individuals are assumed to have identical preferences, this means that once a given group member has provided whatever amount of the good he considers optimal for himself, nobody else has any incentive to make a contribution whatsoever. Thus, we once again confront a case of Chicken, this time with the critical number c_i^o fixed between 0 and 1 for all players: If nobody else cooperates, it is rational for any given player to provide whatever amount of the good he considers optimal for himself. But once any one player does this, nobody else wants to provide any more of it, meaning that when c_i is greater than or equal to 1, D is preferred to C by all players.

Since we are here dealing with public goods that can be provided in optimal amounts by one single player, while at the same time everybody prefers that somebody else pay the cost of provision, we have a situation that in many respects resembles the case that Diekman (1985) labels 'The Volunteer's Dilemma'. However, I do believe that his model belongs to the lumpy goods categories, to be discussed below. The main difference between the two situations is that in the present cases (i.e. categories 3 and 4), the utility curves are monotonously rising with increasing values of c_i. This is because we are dealing with continuous goods, meaning that more contributions may be assumed always to generate greater access to the good in question. This is not the case for lumpy goods, so that in such instances the utility curves will typically be horizontal in some intervals (see below).

As an example of these situations we might think of a group of neighbors sharing a road that has to be cleared of snow in winter.[5] This is an inclusive good, since the utility to each neighbor from having the road cleared will hardly depend on the total number of neighbors.[6] Furthermore, it may be said to be continuous, since the road can be more or less well cleared. Consequently, the utility curves of each player are monotonously rising with increasing values of c_i: As more people cooperate, the road will be in a better condition, even though one single person can provide clearance at an optimal level.[7] In addition, for those already cooperating, further contributors reduce the burden falling on each individual.

This game has n equilibria, all implying that one single player cooperates, while the others defect. Furthermore, all equilibria are Pareto-optimal, implying that the right-hand end-point of the C-curve must lie below the point of the D-curve where $c_i = 1$. Obviously, as in category 2, the players have a coordination problem, implying that the outcome is very difficult to predict in the one-shot-case. Again, however, there may be some reason to believe that with repeated games, the players' choices will converge towards some equilibrium – although we cannot tell which one.

I prefer to postpone the discussion on the possible difference between categories 3 and 4, i.e. the significance of differences in group size, for inclusive goods cases, since this effect is equivalent to the corresponding effect within the Volunteer's Dilemma, to be discussed below.

Lumpy Goods

We now turn to the lumpy goods categories. Since this kind of goods can – by definition – only be provided in more or less massive 'lumps' (or steps), even a small contribution from a single player may sometimes be pivotal for the provision of a large amount of the good. More precisely, *either* a given contribution is pivotal for the realization of the group interest, *or* it doesn't further this interest at all.[8] This means that even if each player gets only a small fraction of the good being provided, it might pay to make a contribution, *given that the sacrifice is pivotal.*

This type of situation may lead to a number of different game structures, dependent on the more specific characteristics of the case under consideration. The perhaps most important of these is the total number of contributions that is needed to provide the good. Three main possibilities exist at this point.

First, it is possible that each and every player can provide the good, i.e. that one single contribution is enough. This kind of situation has been labeled 'Hero' (Hamburger 1979) or 'The Volunteer's Dilemma' (Diekman 1985), since the good can be provided by a hero (i.e. a volunteer), while at the same time everyone involved prefers that somebody else be the hero. Hamburger (1979) gives the following example of the case under consideration:

> ... several people (are) standing on a dock as someone is about to drown. We assume that the principal aspect of utility is satisfaction that the person will not drown, but there is some disutility in getting wet, so the person who goes to the rescue is the hero. (Hamburger 1979, 89)

Obviously, we are here talking about an inclusive good, as the utility of each bystander from the rescue cannot be expected to depend on the number of bystanders. The game can be depicted as shown in Fig. 4.

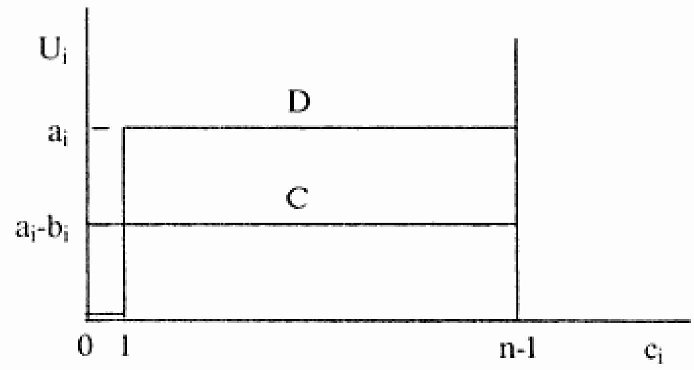

Fig. 4. The Volunteer's Dilemma.

In Fig. 4, player i prefers to cooperate if, and only if, nobody else does. Since we are discussing the provision of a lumpy good, it is assumed that nothing extra can be gained by contributions in excess of what is necessary for establishing the good. This corresponds to there being no gain in more than one person getting wet in Hamburger's example. For this reason, the utility curves in Fig. 4 are horizontal in most intervals (i.e. for c_i greater than 1). The utility of each player from having the good is denoted by a_i, while b_i is the cost of player i from providing the good (i.e. from being the hero).

The game in Fig. 4 contains n equilibria (meaning that there are as many equilibria as there are players) – each equilibrium implying that one person contributes, while all the others defect. In this type of game it seems safe to predict that the greater the number of players, the less the likelihood that the good will be provided – even if we are dealing with an inclusive good. This is due to the fact that for each player, it may seem more likely that somebody else will volunteer, the greater the number of people involved. However, this may be called a 'self-undermining prophecy', since the more everyone believes it, the less true it becomes (Hamburger 1979, 89). It should be noted that this intuitive argument is also supported by more rigorous reasoning. Diekman (1985) has proven that if all players adhere to mixed strategies, the probability (in equilibrium) that anyone will volunteer, is diminished with increasing numbers of players.

The *second* possibility is at the other extreme, in the sense that in this case, the collective good can only be provided if *all* players contribute. A possible illustration can be drawn from Russell Hardin (1982, 51), who mentions *quiet* as a good '... to be desired on a lazy, suburban, springtime Sunday morning ...'. However, to achieve this common goal, it takes unanimous support, since one neighbor with a lawn mower is enough to destroy the silence. Assuming that each resident values the quiet enough to outweigh the disutility from not having his lawn trimmed, the situation can be depicted as shown in Fig. 5.

Again, a_i and b_i represent players i's gains from having the good (i.e. keeping the silence), and the cost of making a contribution (i.e. abstention from trim-

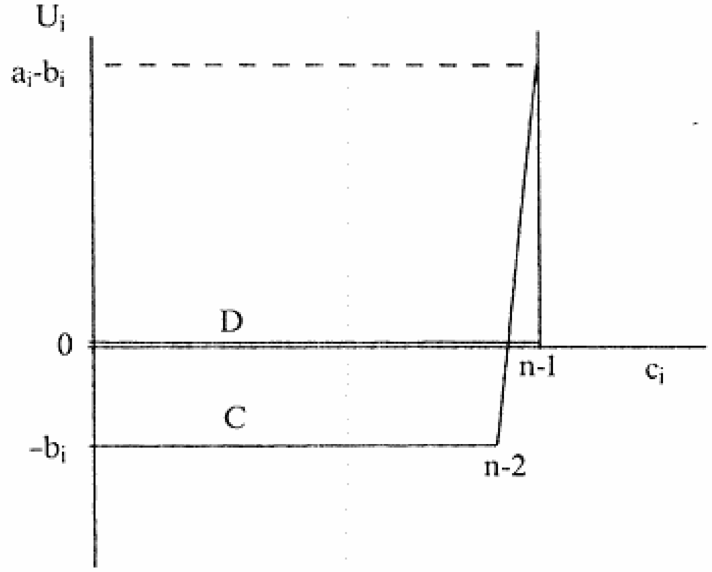

Fig. 5. Provision of Lumpy Goods as an Assurance Game.

ming his lawn), respectively. As can be seen from Fig. 5, it pays for each player to cooperate only on the condition that everybody else does the same thing – otherwise all efforts are in vain.[9] Note that in this game, it is *impossible* to be a free-rider, since one cannot simultaneously enjoy silence in the neighborhood *and* have one's lawn trimmed. This means that $a_i–b_i$ is the highest attainable level of utility for each neighbor.

The game in Fig. 5 can be said to represent a variant of the well-known Assurance Game. It has two equilibria, namely that everyone cooperates, and that all players defect. Of these two outcomes, the former is preferred to the latter by all players. If the participants have perfect information about each others' preferences – which may not be too unreasonable an assumption in the case of a suburban neighborhood – this fact is often presumed to point out the outcome 'all C' as the natural solution of the game. However, in the particular case under consideration here, this solution is extremely unstable, in the sense that defection by one single player will induce noncooperative behavior by all individuals involved. Hence, neighborly quiet on Sunday mornings may be an extremely vulnerable good, in need of constant care by the residents, and being highly sensitive to shortsighted or thoughtless actions by its beneficiaries.[10]

It also deserves mention that with imperfect information among the players regarding others' preferences, the defective equilibrium is even more likely to result. This is true for the Assurance Game in general, but is of particular relevance in our special case. Thus, if one player wrongly suspects even one single of his co-players to value the collective good less than the cost of the contribution demanded from him, it may eventually have the result of defective behavior by everyone involved.

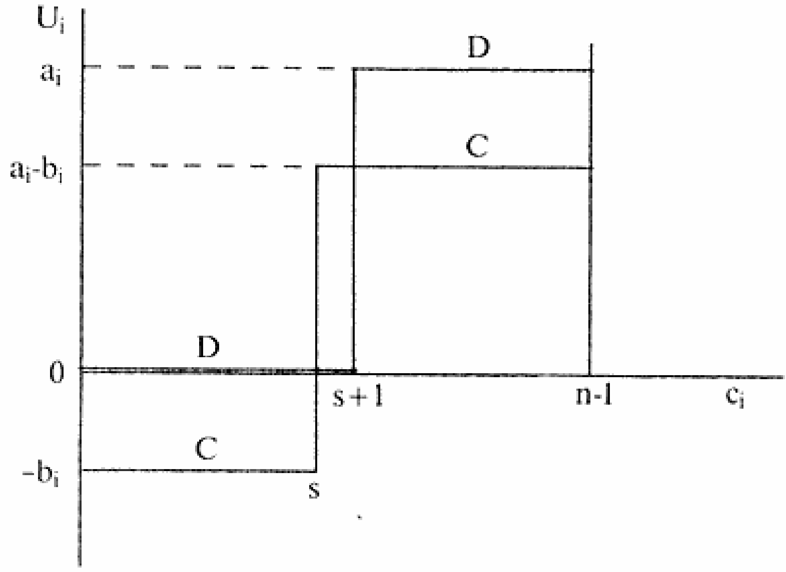

Fig. 6. The Voting Game.

The *final* possibility is that to provide the good, it takes contributions from more than one player, but less than all. An example of this is mentioned by Taylor & Ward (1982, 361). Consider a committee operating under simple majority rule, which is about to decide on some matter. The committee is split into two fractions or coalitions, A and B. Group A consists of s members, all of whom are known to attend and vote *against* the proposal under consideration. Group B has n members ($n>s+1$) and wants a majority in favor of the proposal. It is assumed that if the number of votes against equals the number in favor, the proposal is rejected, making A 'the winner'. Since $n>s+1$, it suffices that less than all n members of B attend to achieve a majority in favor. We also assume that nothing extra can be gained if a majority greater than the minimal one attends, and that to each number of B there is a certain cost of attending (expenditure on travelling, opportunity costs, etc.). The situation can be depicted as in Fig. 6.

It is easily seen from Fig. 6 that if less than s other players (i.e. members of B) attend, player i will prefer to stay at home. The reason is that his presence cannot influence the outcome anyway: No matter what he does, the proposal will be rejected. Similarly, if at least $s+1$ others attend, the proposal will pass whether player i is present or not, so even in this case he prefers not to attend. However, given that exactly s other members of B attend, player i's choice will be pivotal for the committee's decision. Provided that a_i is greater than b_i, player i will then prefer to attend. It is in other words only in those cases where player i is pivotal that he will prefer to attend. It should be noted that this game contains several equilibria. First, it is clear that the outcome where no members of B attend must be an equilibrium. Given that nobody else appears, there is no reason for any given member to show up, so that nobody has any reason to regret his choice if this outcome should result. Furthermore, all outcomes where exactly s+1 members attend must be equilibria. For those who attend, c_i will equal s; they achieve a utility equal to a_i-b_i, and could not have done better by choosing differently. To those who do not meet, c_i equals s+1. Thus, they achieve a utility of a_i, i.e. they reach their most preferred outcome (namely that the proposal passes without them having to attend themselves).

Note that if the number of players attending is different from zero, and also different from s+1, it would have been better for those who attend to stay at home. Hence, no such outcomes can possibly be equilibria.

Is it likely that goods of this category will be provided? Without trying to answer this question in full, a couple of points will be mentioned briefly. First, the game in Fig. 6 bears some resemblance to 'The Volunteer's Dilemma' in the following sense: With increasing group size, and holding s constant, it may once again seem more likely to each player that somebody else will 'do the job'. Hence, even in this case, small groups seem more likely to succeed than large groups. Second, there is an important difference between 'The Voting Game' and 'The Volunteer's Dilemma'. In the latter, each player can guarantee himself that the good is provided, simply by choosing the cooperative strategy. In 'The Voting Game', on the other hand, no such guarantee exists. It seems reasonable to believe that, ceteris paribus, this fact makes provision of the good more likely in 'The Volunteer's Dilemma'.

Before concluding this section, a few remarks should be made with regard to the three models discussed above.

It is clear that the first and the second model are special cases of the third one. Thus, if s=0 (i.e. one vote is enough to pass the proposal), 'The Voting Game' corresponds to the 'The Volunteer's Dilemma'. And if s=n-1 (i.e. only unanimous support in B can secure a majority in favor of the proposal), we have the version of 'The Assurance Game' that was discussed above.

In all three cases there exists at least one equilibrium implying that the collective good is provided. In this respect, the provision of lumpy goods may seem easier to obtain than provision of continuous goods, since in the latter case, universal defection may be the only equilibrium. However, it should be noted that this conclusion is to some extent dependent on the particular rules of the games discussed in this section. Implicitly, it has been assumed that each player faces a choice between making a fixed contribution (e.g. a given sum of money, the cost of attending the committee meeting, the cost of getting wet, etc.), or nothing at all. This seems like a reasonable assumption in some cases, e.g. in the examples discussed above. However, in other cases, it may be more reasonable to assume the existence of some cost-sharing arrangement. As an example, consider a group of fishermen facing the possibility of getting a lighthouse to minimize

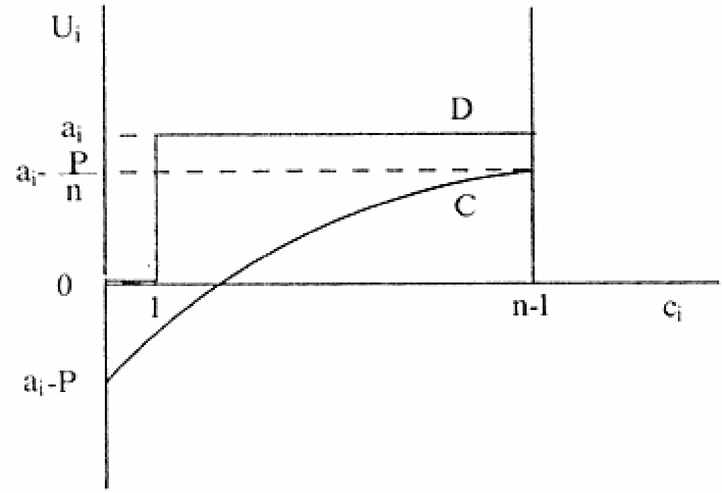

Fig. 7. Provision of Lumpy Goods as a Prisoner's Dilemma.

danger from foul waters and fog near their fishing fields. In such cases, it is likely that the size of each individual contribution will depend upon the total number of cooperators. Suppose that the total cost of the lighthouse is P, and that this cost is split equally on all contributors. The cost b_i for player i will then be P/c_i+1, where c_i once again is the number of cooperators apart from player i. This kind of arrangement may have some intuitive appeal, and one is easily led to believe that it will induce cooperative behavior, since if everyone makes a contribution, the cost to each individual will be small. Somewhat surprisingly, however, self-interested players will under this arrangement typically behave non-cooperatively. To see why, it is useful to have a look at Fig. 7.

If nobody else cooperates, it pays for player i to defect, provided that P is greater than a_i. In Fig. 7, we have assumed this to be the case. Furthermore, once one or more other players cooperate, the good is provided no matter what player i does. Hence, if he is purely self-interested, there is no incentive for him to co-operate whatsoever. Provided that P is greater than a_i, then, this cost-sharing arrangement turns the game into variant of the Prisoner's Dilemma. What actually happens here is that the rules of the game leave each player with only one possibility of being pivotal for the provision of the good, namely when everybody else defects. If the good is not worth its total cost for one single player (i.e. $a_i < P$), the game is a Prisoner's Dilemma. If, on the other hand, $a_i > P$, the game is a Volunteer's Dilemma.

It appears that what makes lumpy goods situations less 'malign' (Underdal 1986) than those involving continuous goods, is the incentive to cooperate created by the prospects of being pivotal. However, such incentives can sometimes be created even in continuous goods situations – e.g. by the use of threats and/or promises. As an example, consider the present situation in the oil market

(Summer 1986). Saudi-Arabia and Kuwait have recently issued commitments not to cooperate unless other OPEC and non-OPEC countries do so as well. To the extent that these commitments are credible, they might turn the game into an Assurance Game, in which the cooperation of each and every exporting country is pivotal for keeping the price up. In other words, if the commitments can be demonstrated to be credible, they might change the incentives facing countries like Norway and (possibly) Britain, making defection no longer a dominant strategy. Since even 'small' producers in such cases may (indirectly) have a great influence on the market, the good under consideration (an acceptable price) may be said to approach a somewhat lumpy character, although it is by nature continuous.

So far little has been said about the importance of group size and nothing about the inclusiveness-exclusiveness-dimension in lumpy goods cases. This is partly because I consider these variables to be of less significance here than when we are dealing with continuous goods. However, a few words seems to be appropriate. First, it has already been mentioned that increasing group size enhances the difficulties of coordination inherent in games of the Volunteer's Dilemma-type, as well as in the Voting Game: The larger the group, the less likely it will appear to each individual that his contribution will be pivotal for the provision of the good. But the more everyone believes this, the less likely it is that the good will be provided at all.

With respect to the Assurance Game-variant, it is also clear that increasing group size enhances difficulties. This is because, in this game, it is of vital importance for each player to know the preferences or the choices of the other players. It is evident that this problem of information is greater, the larger the group in question.

What about inclusiveness? Is it of any importance whether lumpy goods are exclusive or inclusive? It should be noticed that if we disregard the case of the oil market, all examples discussed in this section are of the inclusive-good-variety. The gains to each participant of saving a drowning person, securing a majority, preserving neighborly quiet or providing a lighthouse will not be significantly influenced by the number of players involved. However, it is not difficult to think of exclusive goods with lumpy characteristics. Taylor and Ward's examples of natural resources involving threshold values are notable cases in mind. In such cases a small contribution may sometimes yield a large increase in future use value of the resource, while at the same time the gains to each individual participant depend critically on the total number of agents exploiting the resource. Consequently, it is conceivable that it will not pay to make a contribution – even when this is pivotal for the provision of a large amount of the good – if the number of beneficiaries is very large, so that the player making the contribution will receive only a very small fraction of the gains. Thus, even in lumpy goods cases, instances of inclusive goods tend to be more 'benign' than those involving exclusive goods. However, it nevertheless seems to be the case that continuous goods typically will be more seriously undersupplied than lumpy goods.

Some Asymmetrical Cases

So far the discussion has been confined to instances where all actors can be assumed to take an equal interest in the provision of the public good. In this section, we shall discuss briefly a couple of asymmetrical situations. Because the number of logically possible asymmetries is literally infinite in n-person games, no exhaustive treatment of the various possibilities can be achieved. I have chosen to concentrate on two such situations, which I believe are those most widely discussed in the literature on public goods. Both cases involve a single 'large' actor and several minor ones. The difference is that in the first case the good under consideration is exclusive in character, while in the second case we are dealing with an inclusive good.

Both situations, then, should be modeled as n-person games involving non-identical players. This creates a small problem of exposition. In the previous section we were able to search for equilibria and possible solutions of each game with the aid of only one diagram of the Schelling type. Once non-identical players are introduced, however, this technique breaks down (Hovi & Rasch 1986). This is due to the fact that in general it is now no longer sufficient for a particular player to know only *the number* of other players that choose a particular strategy (e.g. 'cooperation'). It may also be necessary to know exactly *who* these other players are. Fortunately, this problem can be overcome in a relatively simple way by using more than one diagram simultaneously. In our case, where there are two categories of players, two diagrams are needed – one for each category. It is worth noting that this is the case no matter the number of players within each category.

In what follows, I shall first – rather briefly – consider the exclusive goods case, and then at some length discuss an example involving an inclusive good. It should be noted that in both cases we are dealing with continuous goods.

Exclusive Goods

The way that the problem of providing exclusive public goods in asymmetric groups should be modeled can in fact be quite directly traced from the discussion of symmetric groups. The main point is that the fraction f_i (the subscript referring to player no. i is needed here, but not in the symmetric cases) is no longer simply 1/n for all players. Let me suppose that consumption of the good is distributed according to size, and that the 'large' actor is m times the size of each of the minor players. If there are n–1 small players, then f_i equals 1/n–1+m for these actors, while it is m/n–1+m for the large player. Since m presumably is greater than unity (otherwise it would be nonsense to say that we are dealing with a 'large' player), it follows it is more likely that it pays to cooperate for the large player than for the minor ones. If m is sufficiently large, then, we might say that the incentives facing the large player corresponds to those facing players involved in games of category 2 in the previous section, i.e. he has preferences of the Chicken-category. (It may be noted that if m is *very* large compared to n–1, C may even be dominant strategy for the large player.) The small actors, on the other hand, face category 1-incentives, i.e. they have preferences of the Prisoner's Dilemma-type.

This means that in this asymmetric game there is only one equilibrium, namely that the large actor cooperates, while everybody else defects. This outcome may or may not be Pareto-optimal, depending on the more specific character of the players' preferences. However, no matter the Pareto-status of the solution, the model yields predictions that in important respects are similar to those reached by Olson: There is 'the greatest likelihood' that the good will be provided, and the large actor will bear a 'disproportionate share of the burden' (Olson 1965, 29). The logic behind the result is very simple: The large actor knows that if he does not provide the good, nobody will. And since he prefers to bear all of the cost himself rather than to manage without the good, he can do no better than to provide for himself (and for the group) whatever amount of the good he considers optimal for himself. Although this amount is clearly not efficient for the group as a whole, it may be Pareto-optimal if side-payments are not allowed.

For an empirical example that in important ways resembles the case discussed here, one might think of the oil market – at least in certain periods. The good is exclusive (and continuous), and there exists a single actor (Saudi-Arabia) that is far greater than the others with regard to production capacity. It is also hard to deny that throughout the period that OPEC has been in existence, Saudi-Arabia has by far been the country that has carried most of the burdens stemming from production cut-backs.

Inclusive Goods

We shall now see that the predictions obtained above for cases of exclusive goods also seem to hold with respect to inclusive goods. However, the logic behind the predictions is somewhat different.

An example of the problem of providing an asymmetric group with an inclusive public good can be found within many alliances. Article 5 of the North-Atlantic treaty says:

> The Parties agree that an armed attack against one or more of them ... shall be considered an attack against them all. (Pharo & Nordahl 1972, 423)

To the extent that this commitment by the signatories can be considered credible, deterrence of potential enemies is a public good, because the armed forces of one

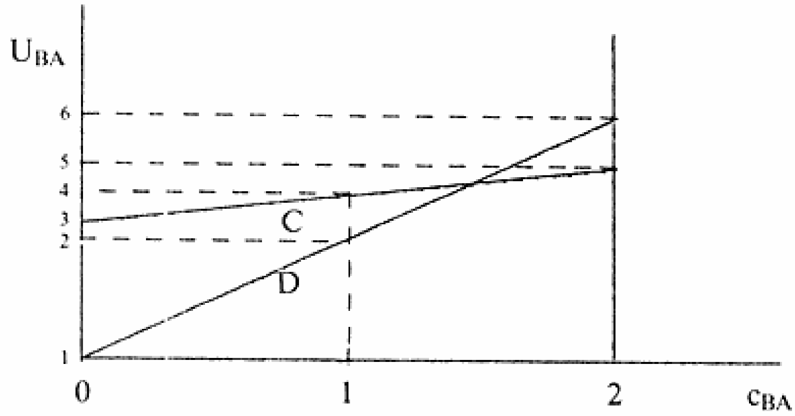

Fig. 8. The Preferences of 'Big Atlantis' in The Alliance Game.

country automatically benefit all members of the alliance. Moreover, we are here dealing with an inclusive good, since in the nuclear age, the deterrence effect of a given amount of missiles, submarines or aircraft does not depend significantly on the number of members in the alliance.

How can we model the game between members of such an alliance? Consider a treaty organization with only three members; Big Atlantis (BA), Little Atlantis 1(LA1) and Little Atlantis 2 (LA2).[11] The two small countries are assumed to be equal in size, while BA is twice the size of each of its allies. It is further assumed that the countries are identical in all relevant respects except size – notably with regard to taste and per capita income. Under these assumptions it is reasonable to assume that in isolation – i.e. if there were no externalities involved – BA would provide for itself exactly twice the amount of defense that would be provided in either of the minor countries (cf. Olson & Zeckhauser 1966). Thus, the unequal size of the countries is accounted for in the model by assuming that a contribution to provision of the good by BA is equivalent to twice the amount of a contribution by either of the minor countries.

We can now consider the preferences of Big Atlantis. These can be depicted as shown in Fig. 8.

Fig. 8 depicts the utility from choosing C and D respectively, as functions of the number of *small countries* choosing C. Note that C is here defined as a contribution equal in size to the level of defense that each country would provide for itself if no alliance existed, while D is defined as no contribution at all. To understand why the curves are drawn the way they are, consider first the possibility that both small countries defect. This is for BA equivalent to complete isolation. Thus, it necessarily prefers C to D in this instance. Next, suppose one of the minor allies cooperates, while the other one defects. For any given choice of strategy by BA, the situation is now clearly preferable (to BA) compared to the

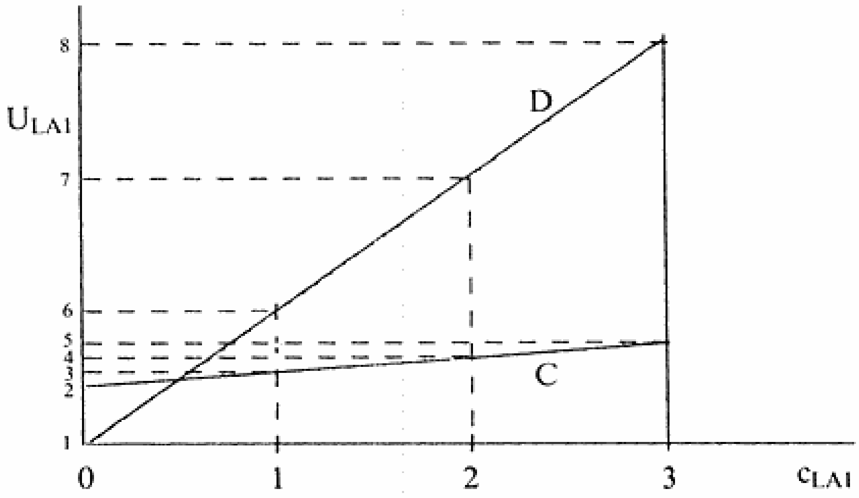

Fig. 9. The Preferences of 'Little Atlantis 1' in the Alliance Game.

case where both small states defect. This always holds true as long as the marginal utility from the good in question (i.e. deterrence) is positive. Thus, the curves for C and D are rising with increasing values of c_{BA}. Whether BA will still prefer C to D when only one of its allies cooperates, depends on the relative size of the large country, compared to the minor ones. The greater the difference in size, the greater the likelihood that BA will still prefer C to D when $c_{BA} = 1$. Note, however, that in our case, where BA is exactly twice the size of either of its allies, there is no compelling reason to assume one or the other on this issue. Nevertheless, I shall make the assumption that BA does prefer C to D when only one of its allies chooses C, as indicated in Fig. 8. Finally, consider the case where both the minor countries cooperate, i.e. where c_{BA} equals 2. If deterrence is a perfectly inclusive good, BA will then be able to consume the exact amount of the good that it considers optimal, even without making any contribution itself.[12] Hence, when $c_{BA} = 2$, Big Atlantis prefers D to C.

Let us now turn to the preferences of each of the small countries. Here, we have to face a problem non-existent in the case of Big Atlantis, namely that it is no longer without importance to the country under consideration *which* other country cooperates (of course, this is relevant only to the extent that only one of them does). This problem can be solved by introducing the notion of *player weights*. In our case, it seems reasonable to assume that either of the small countries will assign weights to its allies according to their potential contributions to the public good, i.e. according to their size. Thus, it is likely that LA1 will assign twice the weight of LA2 to BA. Consequently, c_1 in Fig. 9 is *not* literally the number of countries apart from LA1 that choose strategy C, but rather the number of *player weights* that these countries add up to. If LA2 is the only country apart from LA1 that cooperates, c_1 takes on the value of 1. If, on the other hand, BA is the single cooperator among the allies of LA1, c_1 equals 2. And finally, given that *both* BA *and* LA2 choose to cooperate, c_1 amounts to the value of 3.

What, then, will the preferences of LA1 (or LA2) be? First, it is once again clear that the utility curves for C and D have to be monotonously rising with increasing values of c_1, since this means increasing access to the good in question for any given choice of strategy on the part of the country considered. Second, if nobody else cooperates, LA1 must prefer C to D by the very definition of these strategies. Third, if LA2 cooperates, while BA defects (i.e. if c_1 equals 1), LA1 prefers to defect, because it already has available the exact amount of the public good that it considers optimal for itself. And finally, the same reasoning applies when c_1 exceeds 1, so that this country prefers D to C if, and only if, at least one of its allies cooperates. The same conclusion is of course equally valid as far as LA2 is concerned, since the two minor countries are assumed identical in all relevant respects.

As already noted, the two diagrams in Fig. 8 and 9 provide a complete description of the game being analysed. Hence, we may now turn to the crucial question of what outcome will be the result, given that the game is played non-cooperatively. As in the case of exclusive goods, we find that the game has only one equilibrium, namely that the major actor cooperates, while the minor ones defect. It follows that this outcome is the natural non-cooperative solution of the game. (See the appendix A for proof that this outcome is a unique equilibrium).

Since we are considering a situation involving only three countries, it is possible – without making things too complex – to depict the game in matrix form. This is done in Fig. 10.

Note that the numbers in Fig. 10 (which should be given a strictly ordinal interpretation) have been directly traced from Figs. 8 and 9. The utility of Big Atlantis is indicated down to the left in each cell of the figure. Similarly, the numbers in the middle and in the upper right corner of each cell indicate the utility stemming from that particular outcome for Little Atlantis 1 and 2, respectively. The only equilibrium of the game can be found in the upper right cell of the matrix. This outcome is Pareto-optimal, but – in a certain sense – characterized by an unequal distribution of the gains among the players. While either of the small countries reaches its second highest ranked outcome, Big Atlantis has to settle for the outcome it ranks third from the bottom. Thus, even this model can be said to lend some support to the prediction reached by Olson (1965) and also by Olson & Zeckhauser (1966), namely that in groups with members of unequal size, there is a tendency for the exploitation of the great by the small.

Although the only equilibrium of the game in Fig. 10 is Pareto-optimal, it is important to note that this does *not* follow with necessity from the assumption

Little Atlantis 2		C		D	
Little Atlantis 1		C	D	C	D
Big Atlantis	C	5 / 5 / 5	4 / 8 / 4	8 / 4 / 4	7 / 7 / 3
	D	3 / 3 / 6	2 / 6 / 2	6 / 2 / 2	1 / 1 / 1

Fig. 10. The Alliance Game – Version 1.

made above. Thus, it is perfectly possible that even the two minor countries prefer universal cooperation to the equilibrium. If, for example, the C-curve in Figure 9 is rotated around its intersection with the D-curve in the counterclockwise direction, we may get the situation depicted in Figure 11.

In this case, the equilibrium (which is still located in the upper right corner of the matrix) is Pareto-inferior to the outcome where all three countries cooperate. The distributional aspects of the situation does not, however, differ much from the case in Fig. 10. Thus, Big Atlantis is still the only cooperator in equilibrium, generating an unequal distribution of the gains among the allies. However, this model illustrates a point not mentioned by Olson & Zeckhauser, namely that such a distribution need not necessarily stem from a wish by the minor countries to exploit Big Atlantis. It may equally well be considered an undesirable outcome by the small allies, as well as by the large one. To the extent that this is the case, the situation in a very fundamental sense resembles the more traditional problems of collective action, discussed in earlier sections. This means that there may be gains for small agents, as well as for large ones, from cost-sharing arrangements connected to public goods provision. Thus, quests for such arrangements should not necessarily be considered a purely distributional matter.

To sum up this section, we may concur with Olson's conclusion that in groups with members of unequal size, there is '... the greatest likelihood ...' that public

Little Atlantis 2		C		D	
Little Atlantis 1		C	C	C	D
Big Atlantis	C	7 / 7 / 5	5 / 8 / 4	8 / 5 / 4	6 / 6 / 3
	D	3 / 3 / 6	2 / 4 / 2	4 / 2 / 2	1 / 1 / 1

Fig. 11. The Alliance Game – Version 2.

goods will be provided. This holds true for both exclusive and inclusive goods – at least for those that can be provided in continuously divisable amounts (which are the only ones that have been considered here). Our analysis also lends some support to Olson's hypothesis that in such groups there is a tendency for the exploitation of the great by the small. However, we have also suggested that the logic behind this conclusion is to some extent dependent on whether we are dealing with inclusive or with exclusive goods. In the latter case, we can say that the large group member provides the good because he knows that if he does not, nobody will, and he prefers to pay the full cost rather than doing without the good. In the case of inclusive goods, however, the logic can be stated as follows: If the large group member chooses not to provide any of the good, somebody else probably *will* supply some of it. However, the good will not be provided in the amount that he considers optimal. Therefore, it pays for the large actor to contribute towards the provision of the good. But once the good is supplied in the amount that he considers optimal, nobody else has any incentive to provide any of the good whatsoever.

It is finally worth noting that our discussion of asymmetrical inclusive goods cases has centered on a somewhat special example. The reader should therefore be reminded that with relatively small adjustments in the assumptions made above, we may again face a game involving multiple equilibria – even in the presence of asymmetries. Possibly, this makes the models discussed under categories 3 and 4 of some relevance even here.

Conclusion

In this article, I have tried to categorize different problems of public goods provision, according to their 'score' on 4 variables related to the nature of the good under consideration, as well as to the structure of the group of potential beneficiaries. The main conclusion to be drawn from the discussion is that not all such problems are simply the Prisoner's Dilemma 'writ large' (Axelrod 1984, Hardin 1982). Rather, which game structure that is relevant in a given context depends critically on the specific characteristics of the particular situation under consideration – the Prisoner's Dilemma being merely one out of several possible alternatives.

APPENDIX: *Proof for the existence of a unique equilibrium in the Alliance Game.*

To see that the outcome in question *is* an equilibrium, consider first the situation for Big Atlantis. From Fig. 8 it is easily seen that when nobody else cooperates, i.e. when C_{BA} equals 0, Big Atlantis cannot do anything better than to cooperate. Then turn to the minor countries. The situation where BA is the only cooperator is found in Fig. 9 at the point where $c_{LA1} = 2$ (the situation is equivalent on the part of LA2). As argued in the text, each minor country is then best off by defecting, i.e. by allocating their scarce resources for other purposes than adding further to the available amount of the public good. Thus, when BA is the only cooperator, nobody has any reason to regret its choice of strategy.

To see that this outcome is *the only* equilibrium, consider next the possibility of any *other* outcome being an equilibrium. We have already argued that as long as BA cooperates, each minor country (unconditionally) prefers to defect. This rules out the possibility that any outcome of cooperation by a coalition of players including BA, is an equilibrium. Furthermore, we have seen that any player prefers C to D if nobody else cooperates. Thus, universal defection cannot be an equilibrium. The only remaining possibilities then include the outcomes where one or both of the minor allies cooperate alone. But in these cases either BA would prefer C (this is true if only one of the small states cooperates), or each of the minor allies would prefer D (this is the case if both of them choose C). It follows that no outcome except cooperation by Big Atlantis alone can possibly be an equilibrium.

NOTES

1. Samuelson (1954) holds nonrivalness of consumption to be the defining characteristic of public goods. The same is true for Conybeare (1984), who draws a distinction between Prisoner's Dilemmas on the one hand, and Public Goods Games on the other. It is interesting to note that Conybeare's reasoning at this point seems to be consistent with mine, to the extent that we both hold that the problem of providing goods exhibiting nonrivalness of consumption (i.e. 'inclusive' goods) cannot in general be a Prisoner's Dilemma, see section III below. However, see Fig. 7 for an exception to this general rule.
2. The precise number of cooperators in equilibrium is the smallest integer greater than c_i^o. This holds true provided that c_i^o is *not* an integer itself. If it is, all outcomes where c_i^o *or* c_i^o+1 players cooperate are equilibria. It should also be noted that if the game is asymmetrical, it is possible that there is only one equilibrium in n-person Chicken games. An example of this is given in section V.
3. This means that if X is the total amount provided and X_i the consumption of individual no. i, we have – in the case of a pure inclusive good – that $X_1 = X_2 = \ldots = X_n = X$. For pure exclusive goods, on the other hand, we have that $X_1 + X_2 + \ldots + X_n = X$, which is also true for private goods. See Samuelson (1954), p. 387 for further details.
4. Of course, I do acknowledge that something may be called a 'good' even though potential consumers do not value it enough to outweigh the cost of provision. For example, one may think of a group of people in desperate need of medicine of some sort. Given that they are sufficiently poor, it may be necessary to make an unpleasant choice between medicine and food. Although it would be meaningless to say that the medicine does not represent a 'good' for these people, it is clear that given this very strict budget restraint, nonprovision of the medicine is optimal for the group. However, I do believe that in most cases, this latter criterion is a very practical one for deciding what is, and what is not a 'good' for a given set of consumers: A given object is a 'good' if and only if the consumers consider themselves better off having the object (and paying whatever it costs to provide it). It may be noted that with this definition, whether or not a given object is a 'good' for a set of people depends on these peoples tastes and income, as well as on relevant technology and market conditions (which are important determinants for the cost of providing the object).
5. I owe this example to Bjørn Erik Rasch.
6. At least this holds true if we assume that the area covered by the road is unaffected by increasing numbers of neighbors, i.e. as long as the road itself remains constant.
7. This is true as long as possible 'income effects' are ignored, i.e. as long as we disregard the possibility that the amount of clearance considered optimal may depend on how many others contribute to clearing the road. Since we are dealing with a perfectly inclusive good, what is optimal for one person is also optimal for the group – given that the group is symmetrical.
8. In this section, I concentrate on goods that are either provided in some given amount or not at all. It should be noted that for some good, provision may be possible in several discrete 'steps'. See Hardin (1982), p. 55ff, for some details.
9. Some readers may be somewhat confused by the way that the C-curve is drawn in Fig. 5. An alternative way of drawing it would be to depict it horizontally until reaching the right-hand limit of the diagram, and then rise vertically to the level of a_i-b_i. It is important to note that the two

alternatives are substantially equivalent, since the points on the interval of the C-curve that are placed *between* the points where $c_i = n-2$ and $c_i = n-1$ are not attainable outcomes. Although I feel that the steep rise in the C-curve is best depicted as vertical, I nevertheless found that the solution used in Fig. 5 was more easy to comprehend. What is important, however, is simply that when n-2 others cooperate (i.e. when 1 other player defects), the utility from choosing C is only $-b_i$, meaning that the sacrifice is totally in vain, since the silence is destroyed anyway. And when $c_i = n-1$ (i.e. when everybody else cooperates), the choice of C yields a utility of $a_i - b_i$, since the silence is then preserved.

One should also observe that when the D-curve is completely horizontal, and the C-curve is horizontal when c_i is less than n-2, this means there is no extra damage from more lawn mowers, given that one is already in operation.

10. In cases where the players have continuous action parameters, there may be a further problem, not relevant in the example discussed here. Consider once again the neighbors that needed to clear their common road of snow. Suppose that they have given up on having the road cleared by voluntary actions, and are considering to hire professionals to do the job. Suppose further that the best offer they have got is a given package of fixed cost, so that the good of having the road cleared is now exhibiting a certain lumpiness. The problem of the neighbors is now to raise the necessary funds to pay the professionals. We assume that if one neighbor refuses to pay, the price makes it unprofitable for the rest to go on with the project. We then have a game that in many respects resembles the one in Fig. 5, but with one important difference: There may be several cooperative equilibria, not just one. This is because all outcomes where the total sum of contributions equal the given cost of clearing the road are now equilibria. And since this can be achieved by many combinations of individual contributions, the group faces a bargaining problem not present in the game in Fig. 5. Of course, this may add further to the difficulties of the group, and makes it less likely that the good eventually is provided.
11. The labels are borrowed from Olson & Zeckhauser (1966).
12. Again, this conclusion presupposes that income effects are not present.

REFERENCES

Axelrod, R. 1984. *The Evolution of Cooperation*. New York: Basic Books.

Barry, B. & Hardin, R. 1982. *Rational Man and Irrational Society*. Beverly Hills: Sage Publications.

Chamberlin, J. 1974. 'Provision of Collective Goods as a Function of Group Size', *American Political Science Review* 68, 707–715.

Conybeare, J.A.C. 1984. 'Public Goods, Prisoner's Dilemmas and the International Political Economy', *International Studies Quarterly* 28, 5–22.

Diekman, A. 1985. 'Volunteer's Dilemma', *Journal of Conflict Resolution* 29, 605–610.

Hamburger, H. 1979. *Games as Models of Social Phenomena*. San Francisco: W.H. Freeman & Co.

Hardin, R. 1982. *Collective Action*. London: John Hopkins University Press.

Hovi, J. & Rasch, B.E. 1986. 'Hegemonic Decline and the Possibility of International Cooperation', *Cooperation and Conflict* (forthcoming).

Olson, M. 1965. *The Logic of Collective Action*. Cambridge: Harvard University Press.

Olson, M. 1982. *The Rise and Decline of Nations*. New Haven: Yale University Press.

Olson, M. & Zeckhauser, R. 1966. 'An Economic Theory of Alliances', *Review of Economics and Statistics* 48, 266–279.

Rasch, B.E. & Sørensen, R.J. 1986. 'Organizational Behavior and Economic Growth: A Norwegian Perspective', *Scandinavian Political Studies* 9, 51–63.

Samuelson, P.A. 1954. 'The Pure Theory of Public Expenditure', *Review of Economics and Statistics* 36, 387–389.

Schelling, T.C. 1978. *Micromotives and Macrobehavior*. New York: W.W. Norton.

Taylor, M. & Ward, H. 1982. 'Chickens, Whales and Lumpy Goods: Alternative Models of Public Goods Provision', *Political Studies* 30, 351–370.

Underdal, A. 1980. *The Politics of International Fisheries Management*. Oslo: Universitetsforlaget.

Underdal, A. 1986. 'International Cooperation: Transforming Needs into Deeds', Unpublished.

alternatives are substantially equivalent, since the points on the interval of the C-curve that are placed *between* the points where $c_i = n-2$ and $c_i = n-1$ are not attainable outcomes. Although I feel that the steep rise in the C-curve is best depicted as vertical, I nevertheless found that the solution used in Fig. 5 was more easy to comprehend. What is important, however, is simply that when n-2 others cooperate (i.e. when 1 other player defects), the utility from choosing C is only $-b_i$, meaning that the sacrifice is totally in vain, since the silence is destroyed anyway. And when $c_i = n-1$ (i.e. when everybody else cooperates), the choice of C yields a utility of $a_i - b_i$, since the silence is then preserved.

One should also observe that when the D-curve is completely horizontal, and the C-curve is horizontal when c_i is less than n-2, this means there is no extra damage from more lawn mowers, given that one is already in operation.

10. In cases where the players have continuous action parameters, there may be a further problem, not relevant in the example discussed here. Consider once again the neighbors that needed to clear their common road of snow. Suppose that they have given up on having the road cleared by voluntary actions, and are considering to hire professionals to do the job. Suppose further that the best offer they have got is a given package of fixed cost, so that the good of having the road cleared is now exhibiting a certain lumpiness. The problem of the neighbors is now to raise the necessary funds to pay the professionals. We assume that if one neighbor refuses to pay, the price makes it unprofitable for the rest to go on with the project. We then have a game that in many respects resembles the one in Fig. 5, but with one important difference: There may be several cooperative equilibria, not just one. This is because all outcomes where the total sum of contributions equal the given cost of clearing the road are now equilibria. And since this can be achieved by many combinations of individual contributions, the group faces a bargaining problem not present in the game in Fig. 5. Of course, this may add further to the difficulties of the group, and makes it less likely that the good eventually is provided.
11. The labels are borrowed from Olson & Zeckhauser (1966).
12. Again, this conclusion presupposes that income effects are not present.

REFERENCES

Axelrod, R. 1984. *The Evolution of Cooperation.* New York: Basic Books.

Barry, B. & Hardin, R. 1982. *Rational Man and Irrational Society.* Beverly Hills: Sage Publications.

Chamberlin, J. 1974. 'Provision of Collective Goods as a Function of Group Size', *American Political Science Review* 68, 707–715.

Conybeare, J.A.C. 1984. 'Public Goods, Prisoner's Dilemmas and the International Political Economy', *International Studies Quarterly* 28, 5–22.

Diekman, A. 1985. 'Volunteer's Dilemma', *Journal of Conflict Resolution* 29, 605–610.

Hamburger, H. 1979. *Games as Models of Social Phenomena.* San Francisco: W.H. Freeman & Co.

Hardin, R. 1982. *Collective Action.* London: John Hopkins University Press.

Hovi, J. & Rasch, B.E. 1986. 'Hegemonic Decline and the Possibility of International Cooperation', *Cooperation and Conflict* (forthcoming).

Olson, M. 1965. *The Logic of Collective Action.* Cambridge: Harvard University Press.

Olson, M. 1982. *The Rise and Decline of Nations.* New Haven: Yale University Press.

Olson, M. & Zeckhauser, R. 1966. 'An Economic Theory of Alliances', *Review of Economics and Statistics* 48, 266–279.

Rasch, B.E. & Sørensen, R.J. 1986. 'Organizational Behavior and Economic Growth: A Norwegian Perspective', *Scandinavian Political Studies* 9, 51–63.

Samuelson, P.A. 1954. 'The Pure Theory of Public Expenditure', *Review of Economics and Statistics* 36, 387–389.

Schelling, T.C. 1978. *Micromotives and Macrobehavior.* New York: W.W. Norton.

Taylor, M. & Ward, H. 1982. 'Chickens, Whales and Lumpy Goods: Alternative Models of Public Goods Provision', *Political Studies* 30, 351–370.

Underdal, A. 1980. *The Politics of International Fisheries Management.* Oslo: Universitetsforlaget.

Underdal, A. 1986. 'International Cooperation: Transforming Needs into Deeds', Unpublished.