Full agreement and the provision of threshold public goods

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Abstract: The experimental evidence suggests that groups are inefficient at providing threshold public goods. This inefficiency appears to reflect an inability to coordinate over how to distribute the cost of providing the good. So, why do groups not just split the cost equally? We offer an answer to this question by demonstrating that in a standard threshold public good game there is no collectively rational recommendation. We also demonstrate that if full agreement is required in order to provide the public good then there is a collectively rational recommendation, namely, to split the cost equally. Requiring full agreement may, therefore, increase efficiency in providing threshold public goods. We test this hypothesis experimentally and find support for it.

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1. Introduction

A threshold public good is a public good that is provided if and only if contributions reach a certain threshold. The classic example would be a capital fundraising project where, say, $1 million is needed to build a new school, cancer unit or theatre (Andreoni 1998). The potential applications of the threshold public good concept are, however, far more general than this archetypal example (e.g. Hardin 1982; Taylor and Ward 1982; Hampton 1987, Van Lange et al. 2013). For instance, the fixed costs associated with running any charity, or group activity, require a minimum, and often quite large, amount be reached to make the activity viable. It is crucial, therefore, to understand the conditions under which threshold public goods can be efficiently provided.

The provision of threshold public goods does not generate the tension between individual rationality and group outcomes typically associated with public goods (Bagnoli and Lipman 1989). In particular, there are Nash equilibria where the good is produced at the efficient level. Financing the public good does, however, require people to solve a non-trivial coordination problem, because they must coordinate on how to distribute the cost of providing the public good (Isaac, Schmidtz and Walker 1989). Experimental evidence suggests that groups are not good at solving this problem; the success rate of providing threshold public goods is typically around 40 to 60 percent, even after experience (Croson and Marks 2000, Alberti and Cartwright 2015, Cartwright and Stepanova 2015). Such low success is inefficient and potentially very costly to the group.[1]

This level of inefficiency is intriguing when one takes into account a seemingly obvious solution to the coordination problem, namely, split the cost of providing the good equally (Issac, Schmidtz and Walker 1989). Speaking generally, we know that groups can coordinate well when there is a focal point that aids coordination (Schelling 1960; Mehta et al. 1994; Bardsley et al. 2010). For some reason the ‘split the cost equally’ focal point is not enough, in itself, to help groups coordinate in standard threshold public good games (Issac, Schmidtz and Walker 1989). This is most powerfully illustrated by (Croson and Marks 2001) who find that recommending the equal split did not increase success rates above 60%.[2]

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[1] Various institutions have been considered that can increase efficiency such as voting (Rauchdobler et al. 2010), money back guarantee (Cartwright and Stepanova 2015), and communication (Tavoni et al. 2011, Krishnamurthy 2001). But no silver bullet has been found. We discuss the potential role of communication more in the conclusion.

[2] In more detail, they found that recommending the equal split had no effect on success rates in a symmetric threshold public good game (see below for a definition of symmetry). It did significantly increase success rates in an asymmetric treatment, but only to the level seen in the symmetric treatments, from 48% to 57%.

This raises two fundamental questions: (a) why is the focal point of ‘split the cost equally’ not sufficient to enable coordination in a standard threshold public good game, and (b) is there any way to encourage groups to successfully coordinate using this focal point. Answering these two questions is fundamental in understanding the conditions under which threshold public goods can be efficiently provided. In this paper we offer an answer to both questions. In doing so, we also add to the emerging literature on focal points in asymmetric coordination games (Crawford et al. 2008; Isoni et al. 2013, 2014).

In explaining our approach we begin by noting that the standard threshold public good game sees group members make individual contributions towards the public good. All, therefore, an individual decides is her contribution, e.g. ‘I will contribute $15’. If interaction is repeated (as it is in standard threshold public good experiments) then an individual’s choice can be a signal to others what to contribute (Fatas, Godoy and Ramalingam 2013), or demonstrate commitment to a pattern of contributions (Sell and Wilson 1991). This can be viewed as a form of indirect communication. The messages an individual can send, however, are limited to own contribution.

In applications one often observes the potential for more complex strategies. For instance, a group member may say what everyone in the group should do, e.g. ‘we should each contribute $15’. This allows a richer form of indirect communication. In addition, a group member may make their contribution conditional on others, e.g. ‘I will contribute $15 if and only if everyone else contributes $15’. Such conditional giving changes the rules governing public good provision because agreement is needed. And it is this latter possibility that will be the main focus in this paper. In particular we shall consider a full agreement game that can be briefly described as follows. Each group member specifies a vector of contributions detailing what they and others in the group should contribute. The public good is then provided if and only if every group member states the same vector of contributions (and the sum of individual contributions reach the threshold). Any disagreement amongst group members means the public good is not provided.

We shall demonstrate that the full agreement game has some interesting theoretical properties. We would argue that the game is also of applied interest. To give some context to this, let us consider some applications (which will be discussed more in the conclusion). At one extreme, an individual giving a small donation to charity has little chance to say what others should contribute or make her giving conditional on others. This scenario fits well the standard threshold public good game. At the other extreme consider residents living in an apartment building where unanimity is neccessary in order to progress on some project to change the building. Or, consider decision making in the EU where unanimity is required for a change in policy on, say, the EU budget or common agriculatural policy. These scenarios fit well the full agreement game. The crucial thing is that group members cannot act unilaterally if no agreement is reached. The appartment resident cannot start changing the building without the agreement of others. Similarly, members of the EU cannot change the EU budget without the agreement of others.

Note that the full agreement game pre-supposes some form of instituition that only allows public good provision in the event of agreement. This could be an exogenous institution, such as property right legislation in the case of an apartment building. Or it could be endogenous, as in the case of the EU where state member states have voted to have such an institution. Some institution, though, has to exist. To illustrate the point consider climate change negotiations. Here, countries are not shy in saying what other countries should do. So, we can talk of countries specifying a vector of contributions. It is ultimately, though, up to individual countries (and citizens) how much they contribute to climate change abatement. Europe, for instance, is free to reduce emissions even if the US will not meet previous commitments like those in the Kyoto Protocol. So, climate change (at least at the moment) is not a full agreement game (Gerber and Wichardt 2009, Cherry and McEvoy 2013).

The direct consequence of requiring full agreement is to make the group's task more difficult: Group members not only need to be individually willing to contribute enough to finance the good but also need to agree with each other on what they should each contribute. We will argue, however, that this direct, negative effect can be outweighed by an indirect, positive effects. In particular, the fact that contributions are made conditional on what others do has two basic consequences: (i) it increases the criticality of each individual's decision, while (ii) offering a guarantee that others cannot exploit a willingness to contribute. The prior literature suggests these two consequences will be positive. There is evidence, for instance, that a perception of increased criticality increases contributions (Au, Chen and Morita 1998; De Cremer and van Dijk 2002) and a fear of exploitation discourages contributions (e.g. Isaac et al. 1989; Rapoport and Eshed-Levy 1989). Consider also Bchir and Willinger (2013), who find that the requirement to pay a small fee in order to benefit from a threshold public good increases success at providing the good. This effect partly reflects the reduced chance of exploitation that the fee provides.

A need for agreement can only succeed, though, if group members have the means and desire to coordinate. Increased criticality, for example, can only work if group members know what is expected of them. This is much more likely if there is a focal point around which to coordinate. In short, criticality makes every individual feel as though their decision is necessary in order to achieve a successful outcome, while the existence of a focal point makes it possible for the group members to successfully coordinate. As already discussed, however, evidence from the standard threshold public good game does not seem consistent with a strong focal point. Bchir and Willinger (2013), for instance, found that the introduction of a fee makes a difference by increasing the number of subjects that contribute. It did not increase average contributions or particularly help subjects to coordinate.[3] Will, therefore, group members be able to reach agreement?

To formally analyze the consequences of requiring agreement we apply the seminal theory of focal points due to Sugden (1995). In the theory, a focal point is captured by the concept of a collectively rational recommendation (CRR). The key thing to note at this stage is that CRR is a signficant strengthening on Nash equilibrium. Specifically, if a group member deviates from the CRR then all players (not just the deviating player) become worse off. If a CRR exists then it is unique, but in most games one does not exist. Our main theoretical result can be summarized as follows: (i) in a standard threshold public good game there is no CRR, but (ii) if full agreement is required to provide the public good there is a unique CRR, namely, to split the cost equally. This result explains why members find it difficult to finance the public good in a standard threshold public good game. It also suggests that a requirement for full agreement will help groups coordinate and successfully finance the good, because it increases the prominence of the equal split focal point.

We test experimentally the hypothesis that a need for agreement increases efficiency in providing the public good and find support for it. At this point we remind that a need for agreement inevitably brings with it a richer means of indirect communication because group members specify a vector of contributions. Our experimental design allows us to distinguish whether the opportunity to specify a vector of contributions or the need for agreement is more important in aiding coordination, and we come down strongly on the side of the need for agreement. Indeed, the requirement to specify a vector of contributions appears to make no difference to success in providing the public good. By contrast, a need for agreement increases success, provided subjects are sufficiently experienced. The finding that people can successfully coordinate when they need to reach agreement is consistent with the evidence that

[3] The introduction of a fee may make providing the public good more focal. It does not, however, help coordinate on how to split the cost of providing the public good.

people can coordinate in 'matching games' because of team reasoning or collective rationality (Schelling 1960; Sugden 1993; Mehta et al. 1994; Bacharach 2006, Bardsely et al. 2010).

Recall that the need for agreement has two indirect benefits. The discussion so far has focussed on the benefit of increased criticality. Let us look in more detail at the benefit of avoiding exploitation. A need for full agreement gives each group member veto power over how the public good will be financed. Thus, a member cannot be 'unexpectedly' exploited by others. This may give increased confidence to contribute by solving the assurance problem (Issac et al. 1989; Bchir and Willinger 2013). It does not, however, completely rule out 'exploitation'. In particular, if endowments are asymmetric then the equal split focal point is commonly seen as unfair (see van Dijk and Wilke 1993, 1995). Given that all members contribute the same to the public good one can think of those with a high endowment as exploiting those with a low endowment. This creates a tension between the focal point and fairness, or between efficiency and fairness. Indeed, those with a relatively low endowment may shun the equal split focal point.

The notion that 'unfair' focal points can create a tension in games with asymmetric outcomes is not new (Schelling 1960). Relatively few experimental studies, however, have looked at behaviour in asymmetric coordination games.[4] To explore the tension between focal points and fairness in more detail we compare a setting with symmetric endowments to settings with progressively more asymmetric endowments. In the case where full agreement is required, we find that increasing asymmetry has no effect on success of providing the public good. This suggests that subjects were willing to trade efficiency for equity. Isoni et al. (2013) obtain a similar result when looking at tacit bargaining games.[5] This apparent willingness of subjects to trade equity for efficiency demonstrates the power of focal points.

We proceed as follows: In Section 2 we introduce the threshold public good games we shall study. In Section 3 we provide our main theoretical results. In Section 4 we describe our experimental design and in Section 5 we provide the results. In Section 6 we conclude and relate our results to the recent literature on climate treaties (see, in particular, Barrett 2013, Barrett and Dannenberg 2012, 2014, Tavoni et al. 2011).

[4] Crawford, Gneezy and Rottenstreich (2008) find that slight asymmetry reduces the power of focal points. Other studies, however, paint a more positive picture. For example, Cooper et al. (1993) and Holm (2000) find that a focal point can help players coordinate in the battle of the sexes game.

[5] In the battle of the sexes game all efficient equilibrium are asymmetric and so focal points may merely aid coordination. In a threshold public good game and bargaining game there can be a focal asymmetric equilibrium (e.g. split the cost equally) and a less focal symmetric equilibrium (e.g. split the cost proportionally). This creates a tension between the focal point and fairness.

2. Threshold public good games

We begin by describing what we shall call the standard type of game. The prior literature has focussed on this type of game when considering simultaneous threshold public good games (e.g. Suleiman and Rapoport 1992, Cadsby et al. 2008). The standard type of game will then be contrasted with three other types of game that progressively differ in the feedback given to players, strategy set, and the payoff function. The differences are summarized in Table 1 and will be explained in more detail below.

In all the games we shall consider there is a set of n players $N = \{1, \dots, n\}$. Each player $i \in N$ is endowed with E_i units of a private good where E_i is some positive integer. If $E_i = E_j$ for all $i, j \in N$ then we say the game is symmetric. Otherwise we say that it is asymmetric. There also exist positive integers T and V that we shall refer to respectively as the threshold and the individual value of the public good. The importance of T and V will become clear shortly. To clarify terminology, a particular game is characterized by two things, the type of game – standard, full agreement etc. – and the set of parameters of the game – n, E, T and V.

In a standard game, independently and simultaneously all players must decide how much of their endowment to contribute towards a public good. The strategy set, therefore, of any player $i \in N$ is the set of integers $S_i \equiv \{0, 1, \dots, E_i\}$. A strategy profile $(c_1, \dots, c_n)$ details the strategy of each player, where $c_i \in S_i$ will be called the contribution of player $i \in N$. Let $C = \sum_{i=1}^{n} c_i$ denote total contributions. If total contributions equal or exceed the threshold T then each player receives an additional V units of the private good. We also say that the group was successful in providing the public good. If contributions are below the threshold each contribution is refunded. The payoff of player i, given strategy profile $(c_1, \dots, c_n)$, is, therefore,

$$u_i(c_1, \dots, c_n) = \begin{cases} E_i - c_i + V & \text{if } C \geq T \\ E_i & \text{otherwise} \end{cases} \tag{1}$$

At the end of the game each player is told total contributions, C, but is not told the individual breakdown of contributions. In a standard game with feedback players are informed at the end of the game on the list of individual contributions $c_1, \dots, c_n$, but all other details remain the same. The difference between a standard game and standard game with feedback was considered by Croson and Marks (1998).

In a vector game with feedback the strategy set of a player differs to that of a standard game or standard game with feedback. Independently and simultaneously all players must decide on a vector of contributions saying how much they 'suggest' each player should contribute towards the public good. The strategy set of any player $i \in N$ is, therefore, $S^{CG} \equiv$

$S_1 \times \ldots \times S_n$. Strategy profile $(vc_1, \ldots, vc_n)$ details the strategy of each player where $vc_i = (c_{i1}, \ldots, c_{in}) \in S^{CG}$ denotes the vector of contributions chosen by player i and c_{ij} is the amount that player i 'suggests' player j should contribute. Let $c_i = c_{ii}$ be the amount that player i is willing to contribute and, as before, let $C = \sum_{i=1}^{n} c_i$ denote total contributions. The payoff function remains the same as in a standard game (see equation (1)), and so, given strategy profile $(vc_1, \ldots, vc_n)$, the payoff of player i, is

$$u_i(vc_1, \ldots, vc_n) = \begin{cases} E_i - c_i + V & \text{if } C \geq T \\ E_i & \text{otherwise} \end{cases}$$

Note, that only the value of c_i for all $i \in N$ has any direct bearing on the game. At the end of the game players are, however, informed on the vector of contributions chosen by each player, as well as total contributions. The value of c_{ij} for $j \neq i$ is, therefore, a means of indirect communication between players over time. We know that such indirect communication can make a difference in public good games (e.g. Fatas, Godoy, and Ramalingam 2013).

In a full agreement game the strategy set is the same as in a vector game with feedback but the payoff function is different. The public good is provided if and only if total contributions equal or exceed the threshold and all players choose the same strategy. This means every player must agree on what every other player should contribute, $c_{ij} = c_{lj}$ for any $i, j, l \in N$.[6] Formally, given strategy profile $(vc_1, \ldots, vc_n)$, the payoff of player i is

$$u_i(vc_1, \ldots, vc_n) = \begin{cases} E_i - c_i + V & \text{if } C \geq T \text{ and } vc_1 = \cdots = vc_n \\ E_i & \text{otherwise} \end{cases} \quad (2)$$

At the end of the game players are informed on the vector of contributions suggested by each player, and total contributions, as in a vector game. As discussed in the introduction a full agreement game requires some institution that does not allow public good provision in the event there is not full agreement.

[INSERT TABLE 1 AROUND HERE]

We finish this section by introducing some notation and assumptions that will prove useful in the remainder of the paper. Let $m_i = \min\{E_i, V\}$ and let $M = \sum_i m_i$. Informally, we can think of m_i as the maximum that player i can or will be willing to contribute, and M as the maximum that all players can or will be willing to contribute. We shall use $M_{-i} = M - m_i$ and $C_{-i} = C - c_i$ to denote, respectively, the amount that could be and are contributed by

[6] This does not in any way imply symmetry of contributions, i.e. $c_{ij} = c_{il}$.

players other than i. Finally, we shall assume throughout the following that $M > T$ and $nm_i \geq T$ for all $i \in N$. Thus, it is socially efficient to provide the public good, and players can, if they choose, split the cost of providing the public good equally.

3. Nash equilibria, and focal points

Given that it is socially efficient to provide the public good it is clearly crucial that players collectively contribute the threshold amount, T, or more. Typically, however, there will be many ways to distribute the cost amongst players. This leads to a non-trivial coordination problem with conflict of interest. We begin this section by briefly illustrating how this problem is encapsulated in a multiplicity of Nash equilibria. We then look at whether the existence of a focal point can help players 'resolve the problem' by coordinating on one of the equilibria.

3.1. Nash equilibria

Consider, first, a standard game, and standard game with feedback. In these games, strategy profile $(c_1, \dots, c_n)$ is a Nash equilibrium if and only if $u_i(c_i, c_{-i}) \geq u_i(c_i', c_{-i})$ for all $c_i' \in S_i$.[7] We say the Nash equilibrium is strict if $u_i(c_i, c_{-i}) > u_i(c_i', c_{-i})$ for all $c_i' \in S_i, c_i' \neq c_i$. One can easily derive that strategy profile $(c_1, \dots, c_n)$ is a Nash equilibrium with public good provision if and only if

$$C = T \quad \text{and } c_i \leq V \text{ for all } i \in N.$$

The payoff of player i is $E_i - c_i + V$. Any, ceteris paribus, change in player i's strategy would strictly lower her payoff, either to E_i if she decreases her contribution or to $E_i - c_i' + V$ if she increases her contribution to $c_i' > c_i$.

The assumption that $M > T$ guarantees the existence of several Nash equilibria with public good provision.[8] To illustrate, we refer to Table 2 which introduces three sets of parameters that will be important in the rest of the paper. Strategy profiles $(25,25,25,25,25)$ and $(15,35,25,25,25)$ are two, of many, Nash equilibria that exist with these parameters. Clearly, the first of these equilibria is preferred by player 2, and the second preferred by player 1. More generally, individual preferences over the set of Nash equilibria will inevitably differ

[7] Where $u_i(c_i, c_{-i})$ denotes the payoff of player i if she contributes c_i and the contributions of others are denoted c_{-i}.

[8] There may exist Nash equilibria with no public good provision, but given that every perfect Nash equilibrium is a Nash equilibrium with public good provision (Bagnoli and Lipman 1989), we shall not dwell on this possibility.

At least one such equilibria will exist if $m_i < T$ for all $i \in N$. In this case, player i receives payoff E_i and no, ceteris paribus, change in her strategy would change her payoff.

amongst the group. Hence, there is a conflict of interest between players on how to coordinate and split the cost of the public good (Isaac et al. 1989; Rapoport and Eshed-Levy 1989).

In a vector and full agreement game strategy profile $(vc_1, \ldots, vc_n)$ is a Nash equilibrium if and only if $u_i(vc_i, vc_{-i}) \geq u_i(vc_i', vc_{-i})$ for all $vc_i' \in S^{CG}$. In a vector game strategy profile $(vc_1, \ldots, vc_n)$ is a Nash equilibrium with public good provision if and only if

$$C = T \quad \text{and } c_i \leq V \text{ for all } i \in N.$$

This condition is identical to that in the standard game and standard game with feedback.[9] In the full agreement game strategy profile $(vc_1, \ldots, vc_n)$ is a Nash equilibrium with public good provision if and only if

$$C = T \text{ and } c_i \leq V \text{ for all } i \in N \text{ and } vc_i = vc_j \text{ for all } i, j \in N.$$

Clearly, this adds the additional requirement that all players should agree.

Table 2 details the number of Nash equilibria with public good provision in a standard or full agreement game for each set of parameters. Clearly, the number of equilibria is very large. ‘Standard’ equilibrium refinements do nothing to reduce this number. So, if the problem players’ face is to coordinate on a unique Nash equilibrium then they clearly have a potentially tough problem (Isaac et al. 1989, Asch, Gigliotti and Polito 1993). The experimental evidence with regards to the standard type of game confirms this. While groups successfully provide the public good up to 60 percent of the time (Croson and Marks 2000), it is rare to observe a Nash equilibrium. Perhaps more importantly, groups that do play a Nash equilibrium in one round (of repeated interaction) appear no more likely to play a Nash equilibrium in future rounds (Cadsby and Maynes 1999). This likely reflects the desire of at least one player to transition towards a ‘better for them’ Nash equilibrium. Coordinating on a Nash equilibrium, therefore, is like looking for a needle in a haystack, with the temptation to throw the needle away when you find it in hope of finding a better one. No wonder we observe inefficiency in providing the public good. Or, is there a trick to solving this problem?

[INSERT TABLE 2 AROUND HERE]

3.2. Focal points

We know in general that the existence of a focal point is one means by which players can coordinate on a Nash equilibrium (Schelling 1960). It has been suggested that a threshold

[9] The expansion of the strategy space dramatically increases the number of Nash equilibria. This is because a player’s suggestion of what others should contribute is irrelevant in determining the Nash equilibrium.

public good game has a natural focal point, namely to split the cost of providing the public good equally (e.g. Isaac, Schmidtz and Walker 1989; Suleiman and Rapoport 1992; see also Holmström and Nalebuff 1992). We know, however, that split the cost equally is not a good description of how players behave in the standard type of game (e.g. Isaac, Schmidtz and Walker 1989; Suleiman and Rapoport 1992; Marks and Croson 1999; Croson and Marks 2001; Coats et al. 2009). That leaves the puzzle and challenge discussed in the introduction: why is split the cost not 'focal enough', and is there any way to make it 'more focal'?

To answer these questions it is natural to apply a theory of focal points. In this paper we shall apply the seminal theory of focal points due to Sugden (1995). The theory uses a principle of collective rationality.[10] The basic idea behind collective rationality, or team reasoning, is that a player will recognize a common interest in trying to coordinate on some equilibrium (Sugden 1993; Bacharach 1999). Thus, players look for a decision rule that if followed by all is most likely to produce successful coordination; 'less ambiguous' and 'more obvious' rules should tend to be favoured (Schelling 1960). In order to apply the theory imagine someone giving advice to each player on how much to contribute, or what vector of contributions to suggest. The advice should consist of a decision rule that can be interpreted as a comprehensive plan to play the game (we shall have more to say on this shortly). A recommendation $R = (R_1, \dots, R_n)$ details a decision rule R_i for every player $i \in N$.

A recommendation R is said to be collectively rational (CRR) if there exist payoffs $u_1^*, \dots, u_n^*$ such that (i) if every player $i \in N$ follows her advice R_i then expected payoffs are given by $u_1^*, \dots, u_n^*$, and (ii) if some player $i \in N$ does not follow her advice R_i then, whatever the decision rule of the other players, the expected payoff of any player $j \in N$ is strictly less than u_j^*.[11] The definition of CRR is stronger than that of Nash (or correlated) equilibrium in two important respects: it requires that any deviation from the recommendation results in all players getting a lower payoff irrespective of whether others follow their recommendation. This is a tough condition to satisfy. Tough enough that, in general, there can be at most one collectively rational recommendation and in many games there will be none. Sugden (1995) convincingly argues that if a CRR exists then each player should act on that recommendation. A CRR is thus akin to a focal point of the game.

[10] Gauthier (1975), Bacharach (1993), Casajus (2001) and Janssen (2001) also use variants of the principle of collective rationality.

[11] This definition is a reduced form of the definition given by Sugden (1995). Sugden (1995) allows that advice be conditional on a player's private description of the game and that it can consist of a set of acceptable decision rules. Note also that Sugden (1995) considers a game with two players and we consider the natural extension to more than two players.

In a standard game (or standard game with feedback) one can think of a decision rule as a contribution or set of contributions. Thus, $R_i \subset S_i$, and player i is advised to randomly choose a contribution from set R_i. For example, the advice might be 'contribute 25', $R_i = \{25\}$, or 'contribute something between 25 and 35', $R_i = \{25, \dots, 35\}$. Analogously, in a vector game or a game with full agreement one can think of a decision rule as a vector of contributions or set of vector of contributions. Thus, $R_i \subset S^{CG}$, and player i is advised to randomly choose a vector of contributions from set R_i. For example, the advice might be 'split the cost equally'

$$R_i^E := \left\{\left(\frac{T}{n}, \dots, \frac{T}{n}\right)\right\}$$

or 'contribute zero and split the cost amongst others', which if $i = 1$ gives

$$R_1 = \left\{\left(0, \frac{T}{n-1}, \dots, \frac{T}{n-1}\right)\right\}.$$

Crucial, at this point, is to explain the information players have about the labels in the game. We can contrast the opposite extremes of common knowledge and a scrambled labelling procedure (Crawford and Haller 1990; Sugden 1995). In either case it is assumed that every player knows the parameters of the game, $n, E_1, \dots, E_n, T, V$. What may or may not be known are player labels. With common knowledge every player knows which player is 'player 1' with endowment E_1, and knows that everyone knows that etc. With a scrambled labelling procedure every player knows that there is a 'player 1' with endowment E_1 but they don't know who that player is. This distinction is most easily explained with an example.

Consider the advice 'player n contributes zero and split the cost amongst others'. In the case of common knowledge this equates to

$$R_i = \left\{\left(\frac{T}{n-1}, \dots, \frac{T}{n-1}, 0\right)\right\}.$$

With a scrambled labelling procedure it is ambiguous who player n is. The advice is, thus, more appropriately read as 'let someone else contribute zero and split the cost amongst the rest of us'. This advice, therefore, if $i = 1$, equates to

$$R_1 = \left\{\left(\frac{T}{n-1}, 0, \frac{T}{n-1}, \dots, \frac{T}{n-1}\right), \left(\frac{T}{n-1}, \frac{T}{n-1}, 0, \dots, \frac{T}{n-1}\right), \dots, \left(\frac{T}{n-1}, \dots, \frac{T}{n-1}, 0\right)\right\}.$$

The crucial point to recognise is that the scrambling of labels constrains how specific advice can be. The advice 'let someone else contribute zero ....' is ambiguous because there are $n - 1$ potential candidates for the 'someone else'.

In order to formalize terms in the context of a standard game we say that strategy profile $(c_1, \dots, c_n)$ is an i-permutation of strategy profile $(c'_1, \dots, c'_n)$ if there exists a one-to-one mapping $g: N \to N$ such that $c_j = c'_{g(j)}$ for all $j \in N$ and $g(i) = i$. In short, the contribution of player i remains the same while the contributions of all others are potentially swapped around. We say that there is a scrambled labelling procedure if any permissible decision rule R_i satisfies the following condition: if $(c_1, \dots, c_n) \in R_i$ and $(c'_1, \dots, c'_n)$ is an i-permutation of $(c_1, \dots, c_n)$ then $(c'_1, \dots, c'_n) \in R_i$. We say that there is not a scrambled labelling procedure if any decision rule $R_i \subset S_i$ is permissible. This definition naturally extends to a vector game and full agreement game.

We can now state our main theoretical result. This shows that there exists a collectively rational recommendation if and only if (i) full agreement is required, (ii) labels are scrambled, and (iii) the number of players is sufficiently large. The CRR is to split the cost equally. Intuitively, this is because split the cost equally is unambiguous while all other advice is ambiguous. Recall that collective rationality will favour decision rules that are less ambiguous.

Theorem 1: There exists a collectively rational recommendation if and only if the game is of the full agreement type, there is scrambled labelling, and

$$\frac{T}{nV} < 1 - \left(\frac{1}{n-1}\right)^{n-1}. \qquad (2)$$

When it exists, the collectively rational recommendation is to split the cost equally, $R = (R_1^E, \dots, R_n^E)$.

Proof: Consider a standard game and suppose that $R = (R_1, \dots, R_n)$ is a CRR. Without loss of generality we can assume R_i consists of a single strategy $r_i \in S_i$. Note that it is irrelevant whether labels are scrambled or not. If players follow the recommendation then payoffs are either $u_i^* = E_i - r_i + V$ for all $i \in N$, or $u_i^* = E_i$ for all $i \in N$. Let X denote the set of strict Nash equilibria with public good provision. We know, because $M > T$, that the set X contains at least two equilibria. This means that there exists a strategy profile $(c_1, \dots, c_n) \in X$ that differs from R, in the sense that $c_i \neq r_i$ for at least one player $i \in N$. If players play this Nash equilibrium then payoffs are $u'_i = E_i - c_i + V > E_i$ for all $i \in N$. If $c_i < r_i$ then clearly $u'_i > u_i^*$. If $c_i > r_i$ then either (a) $u_i^* = E_i$ in which case $u'_i > u_i^*$ or (b) there exists some $j \in N$ such that $c_j < r_j$ and $u'_j > u_j^*$. Either way, if players behave according to $(c_1, \dots, c_n)$ rather than R at least one player will receive a strictly higher payoff. This contradicts R being a CRR. A similar argument can be used in a standard game with feedback.

Consider next a vector game and CRR $R = (R_1, \dots, R_n)$. In this case we can assume, without loss of generality, that R_i consists of a single vector of contributions $R_i \subset S^{CG}$. Consider the recommendation $R_i = (0, \dots, 0, r_i, 0, \dots, 0)$ for all i where each player is ‘recommended’ to contribute r_i. This recommendation is valid whether labels are scrambled or not. Using the argument of the previous paragraph we see that this cannot be a CRR. The zeros, however, are merely cheap talk and so changing these cannot make any difference. Thus, there does not exist a CRR.

We turn now to a full agreement game in which labels are not scrambled. Consider a CRR $R = (R_1, \ldots, R_n)$. Again, we can assume that R_i consists of a single vector of contributions $vr_i \in S^{CG}$. Let X' denote the set of strict Nash equilibria with public good provision. We know that X' contains at least two equilibria. Moreover, because there is not a scrambled labelling procedure any strategy profile $(vc_1, \ldots, vc_n) \in X'$ is a permissible decision rule. The argument used for a standard game can now be used again to obtain a contradiction.

Finally, consider a full agreement game with scrambled labelling. Also, consider the recommendation to split the cost equally. If players follow this recommendation then they will play a strict Nash equilibrium with public good provision. Payoffs will be given by $u_i^* = E_i - \frac{T}{n} + V > E_i$ for all $i \in N$. We need to rule out the possibility that a player could expect to do better than this. Without loss of generality we shall attempt to increase the payoff of player 1. To do so, we need that player 1 contributes some amount $\bar{c}_1 < \frac{T}{n}$ and that the public good is provided. The least ambiguous way for others to provide the public good is to split the remaining cost equally. Suppose, therefore, that player 1 uses decision rule

$$R_1 = \left\{ \left(\bar{c}_1, \frac{T - \bar{c}_1}{n - 1}, \ldots, \frac{T - \bar{c}_1}{n - 1} \right) \right\}.$$

The scrambled labelling procedure means that player 2 can only possible agree with player 1 if she uses the decision rule

$$R_2 = \left\{ \left(\bar{c}_1, \frac{T - \bar{c}_1}{n - 1}, \ldots, \frac{T - \bar{c}_1}{n - 1} \right), \left(\frac{T - \bar{c}_1}{n - 1}, \frac{T - \bar{c}_1}{n - 1}, \bar{c}_1, \ldots, \frac{T - \bar{c}_1}{n - 1} \right), \ldots, \left(\frac{T - \bar{c}_1}{n - 1}, \ldots, \frac{T - \bar{c}_1}{n - 1}, \bar{c}_1 \right) \right\}.$$

The same applies for all $i > 1$. The probability of full agreement is given by the probability that every player $i > 1$ randomly selects player 1 to contribute amount $\bar{c}_1$. The probability player i selects player 1 is given by $\frac{1}{n-1}$. The probability that every player $i > 1$ randomly selects player 1 is, therefore, $\left(\frac{1}{n-1}\right)^{n-1}$.

If all players do agree then the payoff of player 1 increases to $E_1 - \bar{c}_1 + V > u_1^*$. If there exists a player j who chooses $vc_j \neq vc_1$ then the payoff of player 1 drops to $E_i < u_i^*$. So, the expected payoff of player 1 is greater than u_i^* if and only if

$$E_1 + \left(\frac{1}{n-1}\right)^{n-1} (V - \bar{c}_1) > E_1 - \frac{T}{n} + V.$$

This is ruled out by assumption. Given that we began with the least ambiguous alternative decision rule that could increase the payoff of player 1, split the cost equally is a CRR. ■

Theorem 1 is potentially a very powerful result. It offers a solution to the puzzle of why split the cost equally is not 'focal enough' in a standard game: split the cost is not a CRR and so it is no surprise that groups fail to coordinate or maintain coordination. In addition, Theorem 1 suggests a novel hypothesis on how efficiency can be increased in threshold public good games: if the existence of a CRR helps players to coordinate then a requirement for full agreement may increase efficiency. It's important to be clear exactly what this hypothesis entails: (i) The direct effect of full agreement is to make coordination more difficult because all players need to agree. (ii) If the existence of a CRR makes it easier for players to coordinate then full agreement may indirectly make coordination easier. If this indirect benefit outweighs the direct cost then a requirement for full agreement can increase efficiency. We view this as an empirical hypothesis to test, and so we shortly turn to our experimental results.[12] Before doing so we shall look in a bit more detail at the role of endowment asymmetry and scrambling of labels.

A scrambling of labels encapsulates two things, that player identity is private information and that endowment is private information. It seems very natural that player identity be private information; for instance, if players agree on the decision rule 'someone contribute zero and split the cost amongst others' it seems unlikely they would all independently know who the 'someone else' should be. This, in itself, is enough to argue that scrambled labelling is the appropriate thing to consider in symmetric games. In asymmetric games, however, the issue of common knowledge warrants more consideration. To illustrate Table 3 gives some decision rules that are conditional on player endowments.[13] Decision rules 'split the cost proportionally' and 'split the cost so payoffs are fair' are intuitive (van Dijk and Wilke 1993, 1995). They are, however, only possible if player endowments are common

[12] The only empirical results we are aware of looking at similar issues are due Van de Kragt, Orbell and Dawes (1983) and Bornstein (1992). In a binary threshold public good game they find that subjects who have agreed with fellow group members how to finance the public good stuck to the agreement. This, however, gives little insight on how group members can successfully reach agreement, particularly in continuous threshold public good games where the task is considerably more difficult. For example, Rauchdobler, Sausgruber and Tyran (2010) find that voting on the size of threshold before playing a threshold public good game makes no difference to efficiency.

[13] See Table 2 for details on the parameters of the symmetric, asymmetric and very asymmetric games.

knowledge. A scrambled labelling procedure, by making player endowments private information, rules them out.

[INSERT TABLE 3 AROUND HERE]

If recommendations such as 'split the cost proportionally' are permissible then there is no CRR in an asymmetric full agreement game.[14] The intuition for this being that there is no sense in which, say, the equal split is any less ambiguous than the proportional split, according to the definition of a CRR. Note, however, that even if player endowments are common knowledge, some players have an 'incentive' to ignore this information in the hope of coordinating on split the cost equally. An expectation that information about endowments may be ignored by at least one player is enough to break common knowledge and make it 'as if' labels are scrambled. One could argue, therefore, that the equal split is focal in a full agreement game even if labels are procedurally not scrambled.[15]

We finish this section by noting how the above argument, and the whole analysis of this paper, depends critically on the 'framing' of the contribution decision. In the games we are considering here group members choose how much of their endowment to contribute. This is the standard framing in the public goods literature. Consider, however, an alternative framing in which group members choose what proportion of their endowment to contribute. Theorem 1 can easily be revised to show that the proportional split is now the CRR in the full agreement game. The framing of the contribution decision clearly, therefore, can make a big difference.

4. Experimental Design

We initially considered four treatments, with each of the four types of game presented in Table 1 corresponding to a treatment. Following the advice of a referee we subsequently considered a further two treatments with variations on the vector and full-agreement game (more details to follow shortly). We reiterate that our standard treatment corresponds to the benchmark

[14] In a symmetric game 'split the cost proportionally' and other alternatives are equivalent to split the cost equally.
[15] This more liberal interpretation of label scrambling would make no difference in a standard game or vector game.

treatment used in the threshold public goods literature. The game used in the standard treatment with feedback, vector treatments, and full agreement treatments differ as detailed in Section 2.

Each experimental session was divided into three parts, as summarised in Table 4. In part 1, subjects played a game with parameters corresponding to those in the symmetric game, as already detailed in Table 2, for 10 rounds. In part 2 they played a game with parameters corresponding to those in the asymmetric game for a further 10 rounds, and in part 3 they played a game with parameters corresponding to those in the very asymmetric game for a final 10 rounds. The type of game played, standard, standard with feedback, vector or full agreement, was the same in all three parts of a session. Note that subjects retained their role within the group throughout a part. Thus, a subject endowed with, say, 70 in an asymmetric game was endowed with 70 in all 10 rounds.

The groups, of five, were randomly assigned at the beginning of each part but remained fixed during the part. Fixed matching during each part of the session allows us to look for dynamic and learning effects as observed in previous threshold public good experiments (e.g. Cadsby et al. 2008). Indeed, given our interpretation of the vector of contributions as a form of indirect communication it is natural to think of the 10 rounds within each part as part of one big game. With this interpretation the final round of the ten takes on special importance as culmination of the game. In this last round there is nothing to be gained by indirect communication and so the only relevant objective is to maximize round payoff.

The use of three different sets of parameters allows us to consider symmetric and asymmetric games.[16] More specifically, the use of the benchmark parameters in part 1 allows an unambiguous comparison of behaviour across treatments in the standard, symmetric case considered in the literature. Parts 2 and 3 allow us to compare behaviour across treatments as subjects are exposed to progressively more asymmetric endowments. Of primary interest is whether groups coordinate on the equal split even though this becomes increasingly inequitable.

[INSERT TABLE 4 HERE]

[16] The random matching between parts potentially allows us to treat the success of groups in one part as independent from the success of groups in other parts. We shall not push this claim too far, as it is natural to imagine some learning effects over the 30 rounds. Note, however, that both the group and game change in each part and so a claim of independence is not too extreme. The data analysis will control for part.

In relating our experiment design to Theorem 1 we remind that Theorem 1 points to three important factors – the type of game, number of players, and label scrambling. Our focus in this experiment is primarily to compare different types of game, and in particular to compare a vector game to a full agreement game. Such focus reflects our belief that the type of game is the most interesting and important factor to consider. In order to focus on the type of game the number of players and scrambling of labels should be fixed throughout. In terms of the number of players, we note that condition (2) is satisfied for all the parameters we consider. In terms of label scrambling, more detailed comment is needed.

The vector and full agreements treatments were designed in a way that player identity was scrambled but endowment was not. So, players in the asymmetric games could have agreed to condition contribution on endowment. Theoretically, therefore, Theorem 1 directly applies to the symmetric game but not the asymmetric games. The instructions given to subjects made, however, no explicit mention of player labelling or how the game would appear to other members of the group.[17] (The instructions are available in online supplementary material.) In line with the reasoning at the end of the previous section we suggest this will likely make it 'as if' labels were scrambled.

Following the comments of a referee we ran two further treatments, labelled vector-S and full agreement-S, in which both player identity and endowment were scrambled. Specifically, subjects were told only own endowment and the distribution of endowments. This did not change the instructions but did make it virtually impossible to condition suggested contribution on endowment.[18] This allows us to explore the effects of label scrambling. More generally, our experiment design allows us to directly test Theorem 1 while also exploring the information that groups choose to exploit.

The experiments were run at the University of Kent (in the UK) with subjects recruited from the general university population. The interactions were anonymous and the experiments were computerized using z-Tree (Fischbacher 2007). We took care to recruit subjects who had not taken part in similar experiments before. We ran 12 sessions in all giving a total of 215 subjects. Subjects were paid in cash at the end of the session an amount equal to their payoff over the 10 rounds multiplied by one pence for one of the three parts. The relevant part was

[17] No subject asked a question about this.

[18] Why 'virtually impossible'? Given that subjects were matched for 10 periods they could have 'signalled' to each other what endowments they have. For example, in the highly asymmetric game anyone that contributes more than 25 must have a high endowment.

randomly selected for each subject. Each session lasted about 40 minutes and the average payment was £6.13.[19]

4.1 Hypotheses

The standard game has been extensively studied in the previous literature and so we 'know' to expect success rates of around 40-60% (e.g. Croson and Marks 2000). Our first hypothesis is that success at providing the public good will be similar in the standard game with feedback and vector game. This is a natural assumption given that there are no strategic differences between these three games.

Hypothesis 1: The success rate of providing the public good is the same in the standard, standard with feedback, and vector and vector-S treatments.

Croson and Marks (1998) compare the standard game and standard game with feedback in a symmetric setting, and find no significant difference in outcomes.[20] We shall extend this by considering asymmetric games and the vector game. Note, however, that Hypothesis 1 is not our main concern and the standard and standard with feedback treatments were primarily included to check consistency of our results with the previous literature.[21]

Our main hypothesis concerns the comparison between a vector game and full agreement game. On the basis of Theorem 1 we argue that groups may be better at coordinating in the full agreement game because of the collectively rational recommendation to 'split the cost equally'.

Hypothesis 2: The success rate of providing the public good in a full agreement and full agreement-S treatments will be higher than that in the vector and vector-S treatments. Groups will agree to split the cost equally.

[19] At the end of each part subjects were asked to fill in a short questionnaire regarding their general experience in the 10 rounds. At the end of part 3 subjects were asked to fill in a further questionnaire. Subjects were not paid for answering the questionnaires but had to answer all of the questions in order to proceed with the experiment. The analysis of the questionnaire responses is beyond the scope of the current paper.

[20] Our standard treatment corresponds to Croson and Mark's (1998) group treatment and our standard with feedback treatment corresponds to their individual-identifiable treatment. They also considered a third, individual-anonymous treatment. Significant differences in outcomes were observed between the individual-anonymous treatment and the group and individual-identifiable treatments.

[21] This is reflected in the relative low number of groups in the standard and standard with feedback treatments. Note, however, that four groups per treatment is not low by the standards of this literature, e.g. Croson and Marks (1998) only consider five groups per treatment.

Hypotheses 1 and 2 together suggest that a requirement of full agreement can increase success rates in threshold public good games. We reiterate that the conditions for providing the public good are much more stringent in a full agreement game than in a vector game. It is far from trivial, therefore, that Hypothesis 2 will hold. It will only hold if all players react to the change in incentives in the way we have predicted.

Our final hypothesis concerns endowment asymmetry. The more asymmetric are endowments the less equitable is split the cost equally. For example in a game with very asymmetric endowments players 1 to 3 get payoff 50 while players 4 and 5 get payoff 125. This creates a tension between the focal point and fairness. Our null hypothesis is that subjects will sacrifice fairness in order to coordinate.

Hypothesis 3: The success rate of providing the public good will be the same in a symmetric, asymmetric and very asymmetric full agreement game.

An alternative to Hypothesis 3 would be to say that when endowments are asymmetric or very asymmetric groups will be less successful at providing the public good. This can occur if those with the smallest endowment 'reject' to split the cost equally on fairness grounds. It can also happen, recalling Theorem 1, if subjects try to coordinate on, say, the proportional split or fair split. Hypothesis 3 encapsulates, therefore, the idea that subjects will act 'as if' information on endowments is scrambled. This idea also feeds into Hypotheses 1 and 2 where the vector-S and full agreement-S treatments are treated as synonymous with the vector and full agreement treatments.

5 Experimental Results

Before we begin analyzing the results let us clarify some issues. We reiterate that our main focus is to compare different types of game and, in particular, to compare the vector and full agreement game. In order to do that we shall compare both: (a) the unscrambled treatments, vector versus full agreement, and (b) the scrambled treatments, vector-S versus full agreement-S. This approach takes into account that the scrambled and unscrambled treatments were run at different times and so there is increased potential for unobserved heterogeneity. If we obtain similar results for both (a) and (b) then our findings appear robust. In an appendix we explore in more detail the role of label scrambling.

5.1 Success Rates

We begin the discussion of our experimental results with some aggregate data on success rates and total contributions. Table 5 summarizes the success rate at providing the public good in the first five rounds and last five rounds of each treatment in each part. Table 6 summarizes total contributions.[22] At the overall level, the success rate is similar in the full agreement treatments as the standard and vector treatments.[23] Look a little deeper, however, and differences emerge. Total contributions are relatively high in the full agreement treatment. There are also some noticeable dynamic differences.

[INSERT TABLES 5 AND 6 AROUND HERE]

These dynamic differences are clearly apparent in Figure 1, which plots the success rate at providing the public good over time in the two full agreement treatments and two vector treatments (ignore, for now, the FULL ALL HP data).[24] Broadly speaking, the success rate appears stable or decreasing across the 10 rounds of each part in the vector treatments while it is increasing in the full agreement treatments. Indeed, in the first round of the full agreement treatments the success rate is always near zero, but by the end of the ten rounds, the success rate reaches 56 percent in part 1 and a relatively high 67 percent in part 2 and 73 percent in part 3. It is also noteworthy that the success rate is increasing across the three parts in the two full agreement treatments (see Table 5). This contrasts with a decreasing success rate in the vector treatment (but not vector-S treatment).

[INSERT FIGURE 1 AROUND HERE]

To more formally test Hypotheses 1 and 2, we report results of random-effects probit regressions with the probability of success as the dependent variable. The vector treatment was used as comparator for the unscrambled regressions and the vector-S treatment for the scrambled regressions. This directly allows us to test whether success was higher in the full agreement treatments than in the vector treatments (Hypothesis 2) and whether success was the

[22] Notice that, in all four treatments, total contributions are obtained by adding up own contributions even if the public good is not provided.

[23] The average success rates and average contributions in the standard treatment are consistent with those observed in earlier studies (e.g. Cadsby et al. 2008).

[24] Given that scrambling makes little difference we provide aggregated data. The standard treatments are omitted to avoid clutter.

same in the vector treatment as in the standard treatments (Hypothesis 1). The results are reported in Table 7.

[INSERT TABLE 7 AROUND HERE]

Consider first the unscrambled regressions. The results in Table 7 confirm an increasing success rate in the full agreement treatment in all three parts. By contrast, in part 1, the success rate is decreasing in the other three treatments; in part 2, it is increasing in the standard treatment but stable in the standard with feedback and vector treatments; in part 3, it is stable in the other three treatments.[25] This is clear evidence of a dynamic difference between the full agreement treatment and the other three treatments. This dynamic effect needs to be weighed against the negative coefficient on the dummy variable for the full agreement treatment. The end result is a prediction of lower success rates in the full agreement treatment in earlier rounds but higher success rates by later rounds. By the end of part 3, for example, success rates are predicted to be 95.2 percent in the full agreement treatment compared to 19.3 percent in the vector treatment and 46.6 and 59.3 percent in the standard and standard with feedback treatments; the difference between the full agreement and vector treatment is highly significant.[26]

Consider now the scrambled regressions reported in Table 7. Here the evidence is less strong, but that is not unexpected given the smaller number of observations. The main thing to note is that we again see a clear dynamic difference between the full agreement-S and vector-S treatments. As before, the success rate is increasing in the full agreement-S treatment. Moreover, the coefficients on FULL and FULL_Round are consistent across the scrambled and unscrambled regressions.

To test whether the success rate was stable across the three parts in the full agreement treatments (Hypothesis 3), we report the results of a random-effects probit regression with a dummy for each part except part 1 (used as a comparator). To account for possible dynamic effects, we also include interaction variables of round crossed with part, as well as a dummy for last round success (which can be ignored for the moment). Table 8 reports the results. In the full agreement treatments we see no evidence of a difference between parts 2 and 1 and

[25] To claim that success rate is increasing in the full agreement treatment in part 1, we need to take account of the negative Round coefficient. Doing so we still find a highly significant effect (Wald test, $p < 0.001$).

[26] To illustrate, consider the 5% confidence intervals for the predicted probabilities of success in the last round. For the full agreement treatment the lower and upper bounds of the confidence interval were, respectively, 0.77 and 0.995. For the vector treatment the lower and upper bounds were, respectively, 0.043 and 0.491.

only weak evidence of a difference between parts 3 and 1. We also tested for a difference between parts 2 and 3 and did not find one (for the average, $p > 0.25$ and round, $p > 0.45$).

For comparison, Table 8 reports analogous results using the vector and standard treatments (other) and vector-S treatment. In the 'other' treatments we observe significantly lower success rates in parts 2 and 3 compared to part 1. That we should observe a lower success rate with asymmetric endowments is consistent with prior results (Croson and Marks 2001). The main thing we would highlight about this finding, is that it suggests the consistency of our results with Hypothesis 3 is not solely due to an order effect. In particular, if the sole reason groups maintain a consistent success rate across parts in the full agreement treatment is due to experience and learning then we would expect to see something similar in the other treatments, and we do not.

The data we have reviewed so far is consistent with Hypothesis 1 in that there is no strong evidence of any significant difference between the two standard treatments and the vector treatments. It is also consistent with Hypothesis 3 in that there is no evidence of a difference in success in the full agreement treatments because of asymmetry. Evaluating Hypothesis 2 is a little trickier. One might have hoped that groups would be able to successfully coordinate in round 1 of the full agreement treatments. Clearly, that did not happen. With experience, however, success rates in the full agreement treatments were high, and significantly higher than in the vector treatments. This provides some support for Hypothesis 2. But, it also suggests we need to look a little bit deeper at how groups were able to learn to successfully provide the public good.

5.2 Coordinating over time

As well as giving the actual success rates in the full agreement and vector treatments, Figure 1 shows the success rate that would have been achieved in the full agreement treatments if the rules for the provision of the public good had been the same as in the vector treatment (the FULL ALL HP line). Observe that success rates would have been very high. This tells us that very different things are causing inefficiency in the full agreement treatments compared to the vector treatments. In the vector treatments we know that any failure to provide the public good must be caused by the total contribution being insufficient. In the full agreement treatments it is clear that failure to provide the public good was primarily caused by a lack of agreement, and not the total contribution being insufficient. This allows us to reconcile the high contributions we observe in the full agreement treatment (see Table 6) with the not so high success rate (see Table 5).

Figure 1 suggests that increasing success in the full agreement treatments reflects groups learning how to coordinate. One way to capture this learning effect is to look at whether group success is permanent or temporary. We know from the previous literature that success in the standard treatment tends to be temporary, i.e. success in one period is no guarantee of success in subsequent periods (Alberti, Cartwright and Stepanova 2013). If groups in the full agreement treatments are learning how to coordinate then we would expect success to be more permanent, i.e. once the group finds how to coordinate they will stick with it. Such a difference between the full agreement and vector treatments would be consistent with Theorem 1 and the notion of collective rationality, provided that groups learn to coordinate on split the cost equally.

We find strong evidence that group success is more permanent in the full agreement treatments. For instance, in the full agreement treatments, 27 out of the 52 groups successfully provide the public good in every round after their first success; this meant sustaining success for an average of 6.0 out of ten rounds.[27] In the vector treatments, only 6 out of the 51 groups sustained successful provision; they did so for an average 5.3 rounds. This difference is significant for both the unscrambled (LR, $p < 0.001$) and scrambled treatments ($p = 0.06$). Also, in the full agreement treatments, initial success was maintained for an average of 4.7 rounds compared to only 3.2 rounds in the vector treatments. This difference is again significant for both the unscrambled (Mann-Whitney test, $p = 0.05$) and scrambled treatments ($p = 0.02$).[28]

To provide some additional evidence we can return to Table 8 and the success(-1) coefficients. Success(-1) is a dummy variable that takes value one if the public good was successful provided in the previous round. In the full agreement treatments we see that success in the previous round is a strong predictor of success in the current round. We also obtain a similar effect in the full agreement and full agreement-S treatments. In the other treatments, consistent with the previous literature, we see that in the symmetric game success in the previous round is not a predictor of success in the current round. In the asymmetric treatments success is more permanent, but still considerably less permanent than in the full agreement treatments.

[27] For simplicity we have aggregated over both treatments and all parts given no observed differences. For example, the numbers for the full agreement treatment are 19 out of 36 groups and for the full agreement-S treatment 8 out of 16. Similar, the numbers are 7 out of 18 in part 1, 11 in part 2 and 9 in part 3.

[28] This holds despite the data for the full agreement treatments being highly censored by the ten round cut off We have no idea how long the 27 groups who successfully sustained provision up to period 10 could have continued to maintain their success.

At this point it is interesting to mention again the findings of Bchir and Willinger (2013). Recall, that in studying symmetric threshold public good games they find that a requirement to pay a small fee in order to benefit from a public good increases efficiency in providing the good.[29] The fee worked by increasing the number of subjects that contribute, rather than enabling better coordination. This leads to important dynamic differences, relative to our findings. In particular, the fee leads to an immediate increase in success but significant inefficiency remains over time. By contrast, we have seen that the need for agreement, decreases initial success but with sufficient experience results in high efficiency. These differences reflect how the need for agreement is a 'stronger' intervention than that of a small fee. This is formally captured by Theorem 1, once we note that the introduction of a fee still leaves no collective rational recommendation.

It remains to question whether groups coordinated on the CRR of split the cost equally. Figure 2 details individual choices in round 10 of each part.[30] We distinguish choices into three categories: split the cost equally, symmetric but inefficient choice, e.g. vector of contributions (30,30,30,30,30), and any non-symmetric choice. In the full agreement treatment the vast majority of choices are symmetric, and the majority of these choices are split the cost equally. Interestingly, however, groups did successfully coordinate on alternatives to split the cost equally. For example, in part 1 we saw groups coordinate on (30,30,30,30,30) and (40,40,40,40,40); in part 2 we saw groups coordinate on (15,15,15,40,40) and (19,19,19,34,34); in part 3 we saw one group coordinate on (9,9,9,49,49).[31]

[INSERT FIGURE 2 AROUND HERE]

The predominance of split the cost equally in the full agreement treatments is consistent with Hypotheses 2 and 3. Indeed, when endowments were very asymmetric, all bar one of the groups that successfully coordinated used split the cost equally. We know that split the cost equally is typically considered unfair (van Dijk and Wilke 1993, 1995). Indeed, it shows up in a preference for the proportional split in the vector treatment (as observed in other studies, e.g.

[29] The threshold public good game considered is different to that considered in this paper in that there was no refund and there was a rebate (in the form of increased public good provision).
[30] We have again aggregated together the full agreement treatments and vector treatments given that the picture is similar in both cases.
[31] We can only speculate on why groups would coordinate on a symmetric but inefficient outcome like (30,30,30,30,30) but we feel it probably reflects a desire to 'be on the safe side'. And, when seen from the point of view of 10 rounds this need not be 'irrational'. Suggesting (30,30,30,30,30) in the first round leaves room for manoeuvre but can then become a focal point for agreement.

Cadsby and Maynes 1998). We see, therefore, strong evidence that subjects were willing to sacrifice equity in order to coordinate on the focal point. As discussed in the introduction this finding is consistent with recent results by Isoni et al. (2013) and points to the power of focal points in asymmetric games. The support we find for Hypothesis 3 is also consistent with the idea that players behave 'as if' information about endowments is scrambled. Some groups did use information about endowments and successfully coordinate on outcomes similar to the proportional or fair split, but the vast majority did not.

6. Conclusions

Many public goods can be implemented as threshold public goods and so it is very important to question whether such goods can be provided efficiently. The experimental evidence to date suggests that inefficiency is to be expected. In this paper we offer an explanation for this inefficiency and a potential solution by applying a model of focal points due to Sugden (1995). To explain the inefficiency we show that in a standard threshold public good game there is no collectively rational recommendation (CRR). This means that there is no 'easy way' for group members to agree on how to split the cost of providing the public good. In offering a solution we show that if full agreement is required to provide the public good then there is a CRR. That recommendation is to split the cost equally.

The need for full agreement encapsulates two things: the chance to specify what others should contribute and a requirement for unanimity. Together these allow each group member to say 'I will contribute if and only if ...'. The strict definition of full agreement that we considered is clearly somewhat stylized. The basic notion, however, that group members can, and would want to make contributions conditional on what others are doing seems very natural. It is encapsulated, for instance, in the matched funding schemes that are commonly used for capital fundraising projects. Less natural is the notion that a strict requirement of full agreement would 'help' groups coordinate. After all, the direct effect of requiring full agreement is to make it more difficult for the group to provide the public good; all group members need to agree. It is, thus, an empirical question whether a requirement of full agreement is a help or hindrance for groups.

We reported experimental results to explore this question. These results show that when group members first interacted, the requirement for full agreement led to significantly decreased efficiency; this reflects the difficulty of all members reaching agreement. With experience, however, efficiency increased and increased to relatively high levels. Our results clearly demonstrate that a requirement for full agreement need not be 'too tough'. Indeed, of the 54 groups in the full agreement treatments only 9 failed to provide the public good at least once. This compares to 4 out of 51 in the vector treatments. Our results also suggest the requirement for full agreement increased criticality as predicted. In particular, success proved relatively permanent when full agreement was required.

Our theoretical and experimental results provide evidence that a requirement for full agreement can increase efficiency. The indirect benefit of increased criticality can overcome the direct cost of requiring agreement. We believe that this finding could be usefully extended to applied settings. As an informal illustration let us contrast EU decision making and climate change negotiations.

A strict notion of agreement, including unanimity, is central to EU decision making. Whether it be the EU budget, trade negotiations with the US, the bailout of Greece, sanctions against Russia, fishing quotas in the Atlantic, or the Syrian refugee crises, full agreement (a few caveats aside) is needed before action can take place. This strictness is often criticized as a potential cause of bottleneck. Many would argue, however, that the EU has been surprisingly successful in achieving its objectives.[32] So, the need for full agreement may be an advantage and not a problem. Note that the EU could change its rules to allow unilateral action. The requirement for full agreement is, therefore, endogenous. Interestingly, rapid EU enlargement has done little to shake the requirement for full agreement on many policy issues.

Contrast EU decision making with climate change negotiations. These negotiations take place without the need for full agreement, as we have defined it (see also McEvoy 2010). In particular, the various international treaties that have been signed leave the onus on individual countries to reduce emissions. In other words, countries are free to act unilaterally. This, we would argue, is a key reason for the lack of progress on climate change abatement (see also Gerber and Wichardt 2009, Cherry and McEvoy 2013). Admittedly, we cannot envisage how an EU style need for agreement could be implemented at the global level. Full agreement is, therefore, unlikely to be the answer. But, at least we gain insight on the problem, namely that environmental treates are not a CRR.

With this in mind let us relate our approach to the recent literature on climate treaties. Barrett (2013) is representative of this literature in implicitly assuming that a treaty will be self-

[32] As an interesting anecdotal example of EU decision making, consider the £1.7bn surcharge the UK was required to pay towards the EU budget in 2014. It would be an understatement to say that this surcharge was unpopular within the UK. The real headline grabber, however, was that France and Germany would receive rebates and so the 'UK taxpayer was subsidising the French and Germans'. It is the vector of contributions and not individual contributions that countries need agreement on. And agree they quickly did.

enforcing if it is a Nash equilibrium (Cherry and McEvoy 2013). Our starting point for this paper was a belief that Nash equilibrium does not appear self enforcing in threshold public good games. As we have discussed above, and will discuss more below, in the experimental lab we repeatedly observe groups deviating from Nash equilibrium. This suggests that a stronger equilibrium concept is needed and we argue that the collectively rational recommendation fits the bill. With this interpretation a treaty would be self-enforcing if and only if it is a CRR. Put differently, a treaty may unravel if it is not a CRR.

In motivating this point suppose (as considered by Tavoni et al. 2011, Barrett and Dannenberg 2012, 2014) that group members are allowed to make a public pledge of how much they plan to contribute before actually contributing. Moreover, suppose the pledges equate to a Nash equilibrium. If one person deviates from their pledge then there is no reason for others to stick to their pledges (Dawes, van de Kragt and Orbell 1988, Chen and Komorita 1994, Tavoni et al. 2011). Indeed, the mere belief that at least one person will deviate from a pledge may be enough for others to ignore theirs (Palfrey and Rosenthal 1991). Note that this incentive to deviate follows because the Nash equilibrium is not a CRR. The results of Tavoni et al. (2011) and Barrett and Dannenberg (2012, 2014) show that many subjects do indeed deviate from pledges. More evidence on the instability of Nash equilibria in threshold public good games is provided by McEvoy et al. (2011) and Croson and Marks (2001). McEvoy et al. (2011) found that around 30% of subjects deviated from a commitment to contribute to public good provision even though this meant they could incur a fine for doing so. Croson and Marks (2001) found that most subjects did not follow a recommended (Nash equilibrium) contribution. By definition a collectively rational recommendation should be immune to such instability.

We are not, however, arguing that a requirement for full agreement is necessarily the optimal way to go. Full agreement requires an authority that may be difficult to implement. Also, as group size increases and the benefits of the public good become highly asymmetric we may find situations in which it does not make sense to require all group members agree. Instead, it may be more appropriate to require some level of agreement below full agreement (Orbell, Dawes and can de Kragt 1990). Indeed, there may be an optimal level of agreement required in order to trade-off the benefit of increased criticality with the difficulty of getting many to agree. It may also be appropriate to consider rounds of cheap talk before a decision has to be made, and to allow side-payments between players that have highly asymmetric endowments. These are issues that can be explored in future work.

The role of cheap talk seems particularly worthy of more consideration. If there is a focal point then communication is likely to be of limited benefit (Schelling 1960, Isoni et al. 2014). If there is no focal point (as we suggest there is not in the standard threshold public good game) then communication may be efficiency enhancing (Van de Kragt, Orbell, and Dawes 1983, Isaac and Walker 1988, Isoni et al. 2011, Palfrey, Rosenthal, and Roy 2015). Evidence on this, however, is lacking. While communication has been extensively studied in linear public good games (see Balliet 2010 for a survey), in threshold public good games the evidence is far more limited. In particular, there is no study, as far as we are aware, that considers communication in the standard game considered in the paper. The evidence we do have is also somewhat mixed (Palfrey and Rosenthal 1991, Ledyard 1995, see also Chamberlin 1978). For instance, Feltovich and Grossman (2015) find that the effect communication has on cooperation decreases as group size increases from 2 up to 15.

Appendix: Label scrambling

Given that the scrambled and unscrambled coordination and full agreement treatments were run at different times there is increased potential for unobserved heterogeneity. So, any comparison of scrambled versus unscrambled treatments needs be tentative. Still, in Table A1 we report the results of random effects probit regressions that make use of all the data. This allows some insight on whether scrambling makes a difference. Note that the communication treatment is used as comparator. Also we have used a dummy for a full agreement treatment (scrambled or unscrambled) and a separate dummy for the full agreement-S treatment. This allows a clearer comparison of whether scrambling makes a difference.

The highly significant coefficients on FULL_ALL reaffirm that success starts from a low base but is increasing in the full agreement treatments. These coefficients can be compared to those in Table 7. Our primary interest here is to see whether scrambling makes a difference. Somewhat surprisingly we find that scrambling makes a difference in part 1. This is a surprise because scrambling is irrelevant for the symmetric game used in part 1. There is evidence, therefore, that we are picking up unobserved heterogeneity. This is why in the main body of the paper we report the unscrambled and scrambled treatments separately.

If scrambling is going to make a difference then this should come in the asymmetric games played in parts 2 and 3. In part 2 we see no evidence that scrambling makes a difference. In part 3 there is weak evidence of a higher success rate when labels are scrambled. This is also reflected in the raw numbers reported in Table 5. We would not, however, want to draw too strong a conclusion from this evidence. Our interpretation of the data is that label scrambling made no difference. This seems an apt point to also mention the results of Marks and Croson (1999). They compare a setting where endowments are public information to settings where endowments are private information. This limiting of information about endowments is not too dissimilar to label scrambling and Marks and Croson find it has no effect on success rates or group contributions.

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Table 1: Comparison of the four games we consider.

Type of game	Feedback	Strategy set	Public good provided
Standard	Total contributions.	Own contribution.	Achieve threshold
Standard with feedback	Individual contributions	Own contribution	Achieve threshold
Vector with feedback	Individual vectors of contributions	Vector of contributions	Achieve threshold
Full agreement	Individual vectors of contributions	Vector of contributions	Achieve threshold and all agree on a vector of contributions

Table 2: The set of parametes used in the experiment, and the number of Nash equilibria in the standard and full agreement game.

	Parameters of the game					Number of Nash equilibria
	N	Endowment		V	T	
		Players 1-3	Players 4-5			
Symmetric	5	55	55	50	125	4,052,751
Asymmetric	5	45	70	50	125	3,075,111
Very asymmetric	5	25	100	50	125	254,826

Table 3: Decision rules for the parameters we consider.

Decision rule	Benchmark	Asymmetric	Very asymmetric
Equal split	(25,25,25,25,25)	(25,25,25,25,25)	(25,25,25,25,25)
Proportional split	(25,25,25,25,25)	(21,21,21,31,31)	(11,11,11,46,46)
Fair split	(25,25,25,25,25)	(15,15,15,40,40)	(0,0,0,62.5,62.5)

Table 4: Experimental design.

Session	Treatment (Type of game)	Part 1 Rounds 1-10	Part 2 Rounds 11-20	Part 3 Rounds 21-30	No. of groups
5	Standard	Symmetric	Asymmetric	Very asymmetric	4
2	Standard with feedback	Symmetric	Asymmetric	Very asymmetric	4
3, 6, 7	Vector	Symmetric	Asymmetric	Very asymmetric	12
1, 4, 8	Full agreement	Symmetric	Asymmetric	Very asymmetric	12
9, 11	Vector S	Symmetric	Asymmetric	Very asymmetric	5
10, 12	Full agreement S	Symmetric	Asymmetric	Very asymmetric	6

Table 5: Success rates over the ten rounds of each part.

	Success rate for provision %									
	Part 1			Part 2			Part 3			Overall
Treatment	First five	Last five	All	First five	Last five	All	First five	Last five	All	All
Standard	55	45	50	40	75	57.5	25	50	37.5	48.3
Standard with feedback	90	60	75	80	60	70	55	55	55	66.7
Vector	73.3	53.3	63.3	50	53.3	51.7	33.3	28.3	30.8	48.6
Full agreement	16.7	53.3	35	21.7	66.7	44.2	36.7	73.3	55	44.7
Vector-S	44	52	48	48	56	52	68	80	74	58
Full agreement-S	20	46.7	33	26.7	70	48.3	56.7	86.7	71.7	51

Table 6: Total group contributions over the ten rounds of each part.

	Average group contribution									
	Part 1			Part 2			Part 3			Overall
Treatment	First five	Last five	All	First five	Last five	All	First five	Last five	All	
Standard	133.5	123.8	128.6	128	134.4	131.2	109	119.3	114.2	124.7
Standard with feedback	156.3	131.8	144.1	134.5	126.9	130.7	126.3	122.7	124.5	133.1
Vector	139.1	122.4	130.7	125	128.9	126.9	108.7	98.25	103.5	120.4
Full agreement	165.7	159.5	162.6	154.3	151.4	152.9	124.4	121.3	122.8	146.1
Vector-S	117.8	110.8	114.3	120.2	121.7	121	130.3	126.3	128.3	121.2
Full agreement-S	151.4	134.6	143	125.4	124.9	125.1	131.3	124.3	127.8	132

Table 7: Results of a random-effects probit regression of the probability of success, round number (Round), treatments (FULL, STF, ST), and interactions between round number and treatment (FULL_Round, STF_Round, ST_Round). The unscrambled regressions use the vector and full agreement treatments. The scrambled regressions use the vector-S and full agreement-S treatments. Standard errors in brackets; * indicates significant at the 10% level, ** at the 5% level, and *** at the 1% level.

Covariate	Part 1		Part 2		Part 3	
	unscrambled	scrambled	unscrambled	scrambled	unscrambled	scrambled
Round	-0.158*** (0.048)	0.002 (0.065)	-0.020 (0.045)	0.032 (0.066)	-0.011 (0.050)	0.032 (0.070)
FULL	-3.572*** (0.590)	-1.329* (0.759)	-2.534*** (0.642)	-2.107** (0.918)	-0.947 (0.668)	-0.874 (0.788)
STF	0.097 (0.722)	-	0.474 (0.761)	-	0.791 (0.854)	-
ST	-1.050 (0.658)	-	-1.193 (0.785)	-	-0.240 (0.916)	-
FULL_ Round	0.460*** (0.078)	0.142 (0.095)	0.393*** (0.083)	0.344*** (0.116)	0.348*** (0.082)	0.186* (0.107)
STF_ Round	0.041 (0.093)	-	0.008 (0.089)	-	0.031 (0.088)	-
ST_ Round	0.098 (0.085)	-	0.248** (0.096)	-	0.102 (0.100)	-
Constant	1.316*** (0.364)	-0.086 (0.512)	0.176 (0.385)	-0.096 (0.583)	-0.754 (0.466)	0.547 (0.565)
No. obs.	320	110	320	110	320	110
No. groups	32	11	32	11	32	11

Table 8: Results of a random-effects probit regressions of the probability of success, round number (Round), part (Part_2, Part_3), last round success (Success(-1)), and interactions between round number and part (Part_2_Round, Part_3_Round) and last round success and part (Part_2_Success(-1), Part_3_Success(-1)). The 'Other' regression includes the standard, standard with feedback and vector treatments. Standard errors in brackets; * indicates significant at the 10% level, ** at the 5% level, and *** at the 1% level.

Covariate	Full agree	Full agree-S	Other	Vector-S
Round	0.161**	-0.086	-0.125***	-0.005
	(0.072)	(0.102)	(0.041)	(0.065)
Part_2	0.454	-0.538	-1.546***	0.027
	(0.614)	(0.730)	(0.474)	(0.65)
Part_3	1.003*	0.659	-1.880***	1.341*
	(0.598)	(0.673)	(0.479)	(0.744)
Part_2_ Round	-0.050	0.243	0.162***	0.012
	(0.099)	(0.151)	(0.057)	(0.094)
Part_3_ Round	-0.108	0.080	0.138**	0.102
	(0.091)	(0.151)	(0.058)	(0.102)
Success(-1)	1.732***	2.55***	-0.135	0.405
	(0.401)	(0.614)	(0.239)	(0.405)
Part_2_Success(-1)	0.094	-1.102	0.807**	0.036
	(0.545)	(0.846)	(0.316)	(0.578)
Part_3_Success(-1)	0.141	-0.772	0.739**	-1.744**
	(0.533)	(0.906)	(0.334)	(0.693)
Constant	-1.822***	-0.946*	1.157***	-0.206
	(0.465)	(0.513)	(0.366)	(0.463)
No. obs.	324	162	540	135
No. groups	36	18	60	15

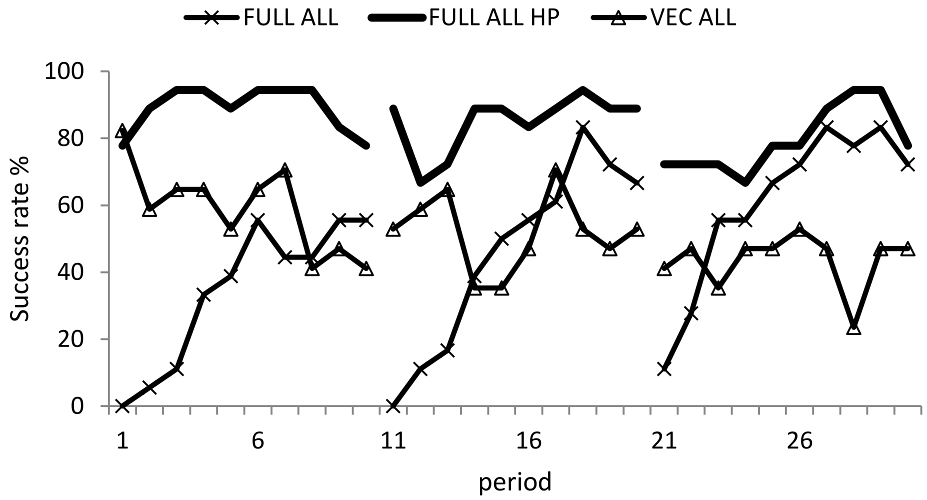

Figure 1: Success rate in the two vector treatments combined (VEC ALL), full agreement treatments combined (FULL ALL), and full agreement treatments if we remove the condition that all players must agree (FULL ALL HP).

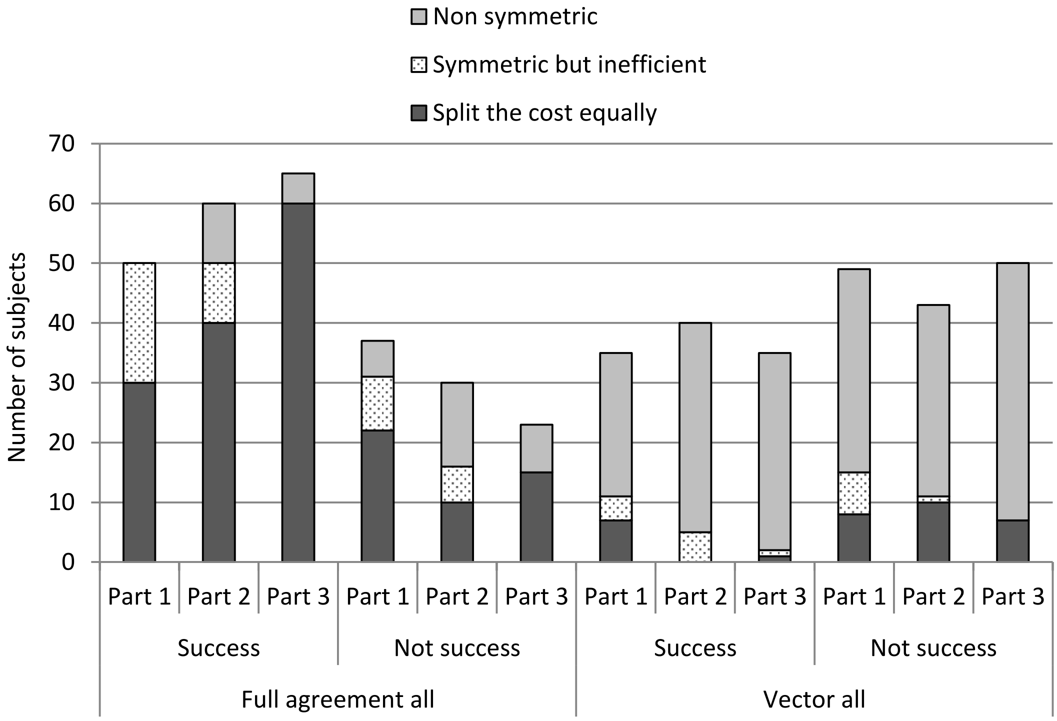

Figure 2: Choices in round 10 of each part distinguished by whether the group was successful or not in providing the public good. The data from the two full agreement treatments and two vector treatments has been aggregated.

Table A1: Results of a random-effects probit regression of the probability of success, round number (Round), treatments (FULL_ALL, STF, ST, FULL_SCRAMBLE, VEC_SCRABMLE), and interactions between round number and treatment (FULL_Round, STF_Round, ST_Round). Standard errors in brackets; * indicates significant at the 10% level, ** at the 5% level, and *** at the 1% level.

Covariate	Part 1	Part 2	Part 3
Round	-0.159***	-0.0202	-0.0113
	(0.0476)	(0.0452)	(0.0495)
FULL_ALL	-3.585***	-2.710***	-0.931
	(0.586)	(0.678)	(0.642)
STF	0.0949	0.474	0.768
	(0.726)	(0.784)	(0.818)
ST	-1.189*	-1.199	-0.241
	(0.658)	(0.808)	(0.879)
FULL_SCRAMBLE	0.870	0.312	1.328*
	(0.689)	(0.852)	(0.784)
VEC_SCRAMBLE	-1.406**	-0.275	1.292*
	(0.619)	(0.711)	(0.779)
FULL_ALL_Round	0.461***	0.421***	0.341***
	(0.0771)	(0.0875)	(0.0802)
STF_Round	0.0411	0.00820	0.0309
	(0.0928)	(0.0890)	(0.0881)
ST_Round	0.135	0.249***	0.101
	(0.0844)	(0.0962)	(0.0995)
FULL_SCRAMBLE_Round	-0.160*	-0.0224	-0.0960
	(0.0901)	(0.114)	(0.102)
VEC_SCRAMBLE_Round	0.161**	0.0523	0.0434
	(0.0800)	(0.0800)	(0.0863)
Constant	1.320***	0.178	-0.730
	(0.365)	(0.396)	(0.446)
No. Obs.	430	430	430
No. Groups	43	43	43