Experimental investigations of coordination games: high success rates, invariant behavior, and surprising dynamics

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Abstract

Binary Threshold Public Good (BTPG) games are central for understanding cooperation and coordination. In the face of their tremendous number of completely different equilibria theoretical predictions about behavior in these games are extremely difficult. In our experiments, four players contribute or not to the production of a public good which is produced if at least \( k \) players contribute. The game with \( k=4 \) is the Stag Hunt game, \( k=1 \) is the Volunteer’s Dilemma. We investigate 16 different games with \( k=1,2,3,4 \). The regularities derived from these extensive variations (e.g. invariance concerning positive vs. negative frames and scaling of players; monotonicity concerning \( k \) and costs of contribution) can serve as the basis of a behavioral theory for BTPG games and beyond.

JEL codes: C72, D72, H41

Keywords: Binary Threshold Public Goods, framing, equilibrium selection, payoff dominance, risk dominance, efficiency, experiment

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Highlights

- With 16 different BTPG games this is the first investigation with systematic variations of frames, thresholds, and cost/benefit ratios.
- Players with the same cost/benefit ratio contribute with the same frequency.
- Negative vs. positive costs and benefits do not cause a framing effect.
- Higher costs (thresholds) are connected with lower (higher) contribution frequencies.
- In the Stag Hunt game, payoff dominance is a better predictor than risk dominance.
- No theory with homogeneous subjects can apply.
1. Introduction

1.1 Motivation and overview

In order to substitute the empty toner cartridge of a publicly used printer only one volunteer is needed who is ready to bear the costs in terms of time lost and dirty hands. This is an example of the Volunteer's Dilemma, first analyzed by Diekmann (1985). More severe than this example are cases where victims of criminal violence or an accident need help, at least in the form of someone calling the police\(^1\). It requires all members of a cartel to keep their contract secret. With plausible assumptions about the profitability of the cartel and incentives for Whistle Blowers, this is an example of the Stag Hunt game, first described by Rousseau (1997 [1776]). A class of examples of this game describes frontlines which have to be defended by individuals or units. These can be military frontlines or dykes or standards of conduct. In the case of dykes, in the past communities (villages) were responsible for keeping their section of the dyke in order.

The Volunteer's Dilemma and the Stag Hunt game are extreme cases of Binary Threshold Public Good (BTPG) games where players have a dichotomous choice of either contributing to the production of a public good or not. Sometimes an intermediate number of volunteers are necessary for the production of a public good, for example when an office party has to be prepared or when a low income friend needs help when moving to another apartment. The public good will be produced if and only if a certain threshold of contributions is reached or surpassed. In this paper the threshold is described as “at least k of n players must contribute”. Player \(i\) bears costs \(c_i > 0\) if he contributes and he enjoys benefits \(G_i > c_i\) if the public good is produced. This structure is completely different from a linear public good game with binary contributions which has a unique equilibrium (no one contributes) while a BTPG game has a plethora of pure and mixed strategy equilibria. No player contributing is one of the equilibria if \(k>1\), but it is (strictly for \(k<n\)) Pareto-dominated by all other equilibria. In the “negative frame” \(G_i < c_i < 0\) it is individually profitable to contribute but players provide a “public bad” when contributions surpass the threshold. An example is CO2 emissions if there is a threshold below which damages are bearable and beyond which catastrophe is inevitable. Voting in

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\(^1\) An often cited example is Kitty Genovese who was stabbed to death in New York City, on March 13, 1964. According to the *The New York Times*, 37 or 38 witnesses saw or heard the attack and did not call the police. (https://en.wikipedia.org/wiki/Murder_of_Kitty_Genovese)
parliaments and in committees as well as shareholder voting is another important example for BTPG games (see Bolle, 2015). In many other examples a team with minimal requirements concerning the number and perhaps also the complementary qualifications\(^2\) of the members is necessary to launch a project or solve a problem for the best of their community.

A rational player's decision is driven by his belief about the contribution probabilities of his co-players. With rather low expectations, she should contribute in the Volunteer’s Dilemma \(k=1\) but never for other thresholds. With rather high expectations, she should contribute in the Stag Hunt game \(k=n\) but otherwise free-ride. The cases \(1<k<n\) are highly ambiguous with respect to beliefs about others’ decisions. Often, two completely mixed strategy equilibria coexist where in one equilibrium strategies are strategic complements and in the other strategic substitutes.

Our investigation is the first which systematically varies

(i) the threshold (\(k=1, 2, 3, 4\) contributions from four players are necessary)

(ii) cost/benefit ratios in a game (identical, small differences, large differences)

(iii) scales (subjects with different costs and benefits but the same cost/benefit ratio)

(iv) positive versus negative frame

Compared with the alternative of concentrating on the support or the falsification of a special theory in a narrow environment, such a broad investigation of influences avoids a selection bias. For that purpose, it is important to report and consider unsurprising and surprising, intuitive and counter-intuitive results as well as confirmations and rejections of theories, all with the same attention. We have clear results concerning our four experimental variations and, therefore, these results may guide a theory of behavior in BTPG games and beyond (Bolle, 2017). For behavioral theories derived from independent principles such a detailed description is a greater challenge than any “single result investigation”.

Ad (i): In order to preserve a high probability of success subjects should, with increasing thresholds, increase their contribution frequency. This requires, however, enough trust in

\(^2\) “Complementary qualifications” require a generalization of the threshold definition. In Bolle (2015) the threshold is described by sufficient subsets of players as in cooperative games with binary characteristic functions (called simple cooperative games or voting games).
the contributions by others. This dilemma has not been investigated with variable thresholds but mainly for the Stag Hunt (k=n). Our investigation contributes, with four different games, to the old question of whether in the Stag Hunt game the pay-off dominant or the risk dominant equilibrium is played and, with 16 games in four different treatments, to the new question of whether or not the contribution frequencies increase with the threshold.

Ad (ii) Except for the Volunteer’s Dilemma (k=1), there are no experiments with different cost/benefit ratios. Diekmann (1993) found that contribution frequencies of players decrease with their increasing cost/benefit ratios which is plausible but counter to theory. We confirm his result in eight different games also for thresholds k>1.

Ad (iii) and (iv): Theoretically, in completely mixed strategy equilibria, players with the same cost/benefit ratio contribute with the same probability. Games which differ only with respect to the sign of costs and benefits are equivalent (to be explained in more detail below). We largely confirm these invariances for BTPG games which is surprising on the background of experimental results in other games, in particular the framing effects in the case of linear Public Good games.

In the process of controlling for dynamic behavior in our repeated games we find that pivot players increase their contribution frequencies in the next round which has previously been found in sequential BTPG games (see below). This is a new result and also a bit astonishing because we have a stranger design, i.e., in every round of the repeated game, randomly a new experimental group is formed. After controlling for pivot player behavior the experimental results do not show a significant trend over 32 periods (four games in a random order with eight repetitions).

After discussing the relevant literature, Section 2 presents some theory of BTPG games (as far as necessary for the evaluation of the experimental results). Section 3 describes the experiment and, in Section 4, four main hypotheses are formulated. Section 5 provides results which are discussed in Section 6.

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3 If there are exactly k contributions, then all contributing players are pivot players; if there are exactly k-1 contributions then all non-contributing players are pivot players.
1.2 Literature

Most previous studies have analyzed only one or two experiments or treatments. Exemptions concern mainly group sizes (Franzen, 1995, investigating the Volunteer’s Dilemma and Feltovich and Grossman, 2013, the Stag Hunt game) while our group size is always n=4. Diekmann (1993) investigates Volunteer’s Dilemma games with two group sizes and three cost variations and Battalio et al. (2001) Stag Hunt games with one group size and three cost variations.

Experimental results of the Volunteer’s Dilemma (k=1; Diekmann, 1993; Franzen, 1995) reject theoretical predictions about success probabilities (decreasing with group size) and about the order of contribution frequencies (low cost players contribute more often than high cost players). Przepiorka and Diekmann (2013) and Diekmann and Przepiorka (2015) find, in the Volunteer’s Dilemma, a tendency towards the equilibrium where only the lowest cost player contributes.

Experimental studies of the Stag Hunt game (k=n) are mostly based on 2x2 games and are concentrated on the question of which of the two pure strategy equilibria “no one contributes” (mostly selected by risk dominance) and “all contribute” (selected by payoff dominance) is played. Van Huyck et al. (1990) and Rydval und Ortmann (2005) find tendencies towards risk dominance; tendencies towards payoff dominance are found by Battalio et al. (2001), provided the “optimization premium” is high enough, and, in an experiment with chimpanzees, by Bullinger et al. (2011). Whiteman and Scholz (2010) find a positive influence of social capital. Al-Ubaydli et al. (2013) find that cognitive ability and risk aversion have no impact on successful coordination while patience does. Büyükboyacı (2014) shows that information about the risk attitude of others changes behavior which is, however, not affected by one’s own risk attitude. Our results (based on 4x2 games) support payoff dominance in the Stag Hunt game (4% - 26% deviations in the four treatments). Feltovich and Grossman (2013) investigate the influence of group size (2 to 7 players) and communication. Without communication, contributions are independent of group size, between 37% and 45%, and thus considerably deviate from the predictions of risk dominance as well as payoff dominance.

Experiments with intermediate thresholds require contributions from two of three players up to six of ten. Only Goren et al. (2003) investigate a BTPG game with five players with different weights (5, 10, 15, 20, 25) and a threshold which requires the sum
of weights to be at least 30. With the exception of Palfrey and Rosenthal (1991) all experiments are with complete information about monetary payoffs. Van de Kragt et al. (1983) and Palfrey and Rosenthal (1991) emphasize the importance of communication for successful coordination. Dawes et al. (1986) and Rose et al. (2002) investigate the (positive) influence of refunds of insufficient contributions and Dawes et al. (1986) also the punishment of successful free riding. Goren et al. (2003) find that the sequential-moves game leads to more efficient outcomes than the simultaneous-moves game and Erev and Rapoport (1990) show that, in addition, the information provided to the players in the sequential game matters. Erev and Rapoport (1990), Chen et al. (1996), and McEvoy (2010) find that, in sequential decisions, the pivotality (criticality) of players increases the contribution frequency. Bartling et al. (2015) find that pivotality increases responsibility attribution. Sonnemans et al. (1998) is, to the best of our knowledge, the only BTPG experiment where players contribute under a positive and under a negative frame. It will be described in more detail in Section 5.

There are more experimental investigations of Threshold Public Good games with non-binary contributions and payoff functions with two steps. For an overview see Fischbacher et al. (2011) and Norman and Rau (2015), for framing effects in such games see Brekke et al. (2017).

2. Equilibria and equilibrium selection

A more general theory of BTPG games is developed in Bolle (2015). Here we concentrate on games with players who have equal importance for passing the threshold. In the positive frame, there is a set of players \( N = \{1, \ldots, n\} \) who can contribute (with costs \( c_i > 0 \)) or not (without costs) to the production of a public good. If the threshold of \( k \) contributions is reached or surpassed, the public good is produced (the project is launched) and the players earn \( G_i > c_i \). There are \( \binom{n}{k} \) pure strategy equilibria with the launch of the project where exactly \( k \) players contribute. For \( k > 1 \), there is one pure strategy equilibrium without the launch of the project where no one contributes. Only the latter equilibria and the “all contributing” equilibrium of the Stag Hunt game (k=n) are symmetric pure strategy equilibria. With equal (different) cost/benefit ratios mixed strategy equilibria are symmetric (asymmetric). The symmetry case is proved in Bolle (2015).
The case $G_i < c_i < 0$ is called the negative frame. It can be transformed into the positive frame. For a formal proof see Appendix A.

**Strategically neutral transformation:** By renaming “contribution” as “non-contribution” (and vice versa), exchanging thresholds $k$ and $n - k + 1$, and renormalizing utilities so that again “non-contribution/ non-launch” has a value of zero, the negative frame is transformed into the positive frame.

As an example let us regard $k=n$ in the negative frame. It is in the interest of all players that the “public bad” is not produced, i.e., in the case $k=n$ one of the players must incur the opportunity costs of not contributing (not collecting the negative costs). Renaming this behavior as “contribution” the case $k=n$ in the negative frame is equivalent with the case $k'=n-k+1=1$, the Volunteer’s Dilemma, in the positive frame. Renormalization has no strategic impact because only income differences between contributing and non-contributing matter; but if we want to reach the same incomes as in the positive frame we have to add the constant income $c_i - G_i$ to i’s income from his decisions. (In the negative frame, $G_i$ and $c_i$ are negative.)

Let us now assume that the players’ contribution probabilities are $p = (p_i)_{i=1,...,n}$. $Q = Q(p)$ denotes the probability of success, i.e., that $k$ or more players contribute to the production of the public good. $Q_{-i}$ ($Q_{+i}$) denote the probability of success if $i$ does not contribute (contributes). The latter probabilities dependent only on $p_j$, $j \neq i$. $q_i = Q_{+i} - Q_{-i}$ is the probability that $i$’s contribution is crucial for the production of the public good.

With these definitions player $i$’s expected revenue is

1. $R_i(p) = G_i \cdot Q(p) - p_i c_i$
   
   $= G_i \cdot Q_{-i} + p_i \cdot [G_i \cdot q_i - c_i]$.

A mixed strategy equilibrium with $0 < p_i < 1$ requires that $R_i$ is independent of $p_i$, i.e.,

2. $\frac{\partial R_i}{\partial p_i} = G_i \cdot q_i - c_i = 0$.

This requirement has been derived verbally by Downs (1957, p. 244) for the binary decision of voting or not. If $G_i \cdot q_i - c_i < (>) 0$ then player $i$ contributes with $p_i = 0 (1)$. Inserting $q_i$ from (2) into (1) provides us with the equilibrium profit which $i$ expects if she plays a mixed strategy.

3. $R_i = G_i \cdot Q_{-i} = G_i \cdot Q_{+i} - c_i$. 


Proposition 1: The following statements apply in equilibrium:

(i) If \( i \) plays a strictly mixed strategy, then \( q_i = r_i = c_i/G_i \).
(ii) If \( G_i > ( <) 0 \), \( q_i > r_i \) implies \( p_i = 1(0) \) and \( q_i < r_i \) implies \( p_i = 0(1) \).
(iii) \( R_i = G_iQ_{-i} \) applies for \( p_i < 1 \) and \( R_i = G_iQ_{+i} - c_i \) for \( p_i > 0 \).

Proof: (i) and (ii) follow from (2). (iii) follows from (3) and, for \( p_i = 0 \) or 1, from (1) and \( p_i = 0 \) implying \( Q = Q_{-i} \) and \( p_i = 1 \) implying \( Q = Q_{+i} \).

In the positive frame, the case \( k = n \) is the Stag Hunt game, first discussed by Rousseau (1997 [1762]). There are two symmetric pure strategy equilibria, namely \( p = (0, \ldots, 0) \), \( p = (1, \ldots, 1) \) and, possibly, a completely mixed strategy equilibrium which is derived from Proposition 1 (i), \( r_i = q_i = \Pi_{j \neq i} p_j \). Multiplying all these equations we get \( \Pi_j r_j = \Pi_j p_j^{(n-1)} \) and \( (\Pi_j r_j)^{1/(n-1)} = \Pi_j p_j \). After dividing this equation by the first equation we get

\[
(4) \quad p_i = \left(\frac{\Pi_j r_j}{(n-1)}\right)^{1/(n-1)}/r_i.
\]

The condition of the existence of this equilibrium is \( p_i < 1 \) for all \( i \). This condition is always fulfilled for \( n=2 \) or if all \( r_i \) are identical. Smaller \( r_i \) are connected with larger \( p_i \). Because of (3) and \( Q_{-i} = 0 \) the mixed strategy equilibrium yields zero profits. Because of Proposition 1 (iii), \( p = (1, \ldots, 1) \) is the payoff-dominant equilibrium, i.e., it is Pareto-superior to all other equilibria.

In the appendix, we determine the risk dominant equilibrium under the definition of Harsanyi and Selten (1988) which is based on their tracing procedure. Risk dominance tries to draw the line between situations where we should rely on the contributions of others and situations where the risk that at least one of them does not contribute is too large. (Only for the case \( n=2 \) a simple characterization of the risk dominant equilibrium is available.) In Bolle (2017) also the Global Games equilibrium selection (Carlsson and van Damme, 1993) is applied to the Stag Hunt game. For our experimental games, both principles select \( p = (0,0,0,0) \).

Proposition 2: In the case \( k=n \), if \( r_i > \Pi_{j \neq i} (1 - (r_j)^{1/(n-1)}) \) for all \( i \) then \( (0, \ldots, 0) \) risk dominates all other equilibria.

Proof: Appendix A.
Corollary: In Treatments S+ and S- with identical cost/benefit ratios 0.4 and in treatments A and B with cost/benefit ratios (0.225, 0.25, 0.275, 0.3) and (0.1, 0.2, 0.3, 0.4), the risk dominant equilibrium in the game with k=4 is p = (0, ..., 0).

In the positive frame, the case \( k = 1 \) is the Volunteer’s Dilemma, first investigated by Diekmann (1985, 1993). There are \( n \) pure strategy equilibria where exactly one player contributes. The only completely mixed strategy equilibrium is derived from Proposition 1 (i), \( r_i = q_i = \prod_{j \neq i} (1 - p_j) \). Multiplying all these equations we get \( \prod_j r_j = \prod_j (1 - p_j)^{(n-1)} \) and \( \left( \prod_j r_j \right)^{1/(n-1)} = \prod_j (1 - p_j) \). After dividing this equation by the first equation we get

\[
(5) \quad p_i = 1 - \left( \prod_j r_j \right)^{1/(n-1)}/r_i.
\]

Therefore, this equilibrium exists under the same conditions as that of the Stag Hunt game. Smaller \( r_i \) are connected with smaller \( p_i \) (regarded as counter-intuitive by Diekmann, 1993). Because of Proposition 1 (iii) and \( Q_{+i} = 1 \), in this equilibrium players earn \( R_i = G_i - c_i \), i.e., as much as players who contribute with certainty.

If \( 1 < k < n \), then completely mixed strategy equilibria, if they exist, usually have to be determined by numerical methods. If all \( c_i/G_i = r_i = \rho \) are equal, then, in a completely mixed strategy equilibrium, the symmetric equilibrium \( p_i = \pi \) is of major interest. (In our experimental cases no asymmetric equilibrium exists.) \( \pi \) is derived from

\[
(6) \quad \rho = q_i = \left( \frac{n-1}{k-1} \right) \pi^{k-1} (1 - \pi)^{n-k}.
\]

For \( 1 < k < n \), the right hand side of (6) is a unimodal function of \( \pi \) with a maximum at \( (k - 1)/(n - 1) \). Therefore (6) has either two solutions \( \pi''(k) > \pi'(k) \) (for small enough \( \rho \)) or one solution (border case) or no solution; i.e., either completely mixed strategy equilibria do not necessarily exist or, generically, there are two. In the positive frame, the equilibrium with \( \pi'' \) Pareto-dominates the one with \( \pi' \) and vice versa in the negative frame (Proposition 1 (iii)). In the positive frame, in the equilibrium with \( \pi''(\pi') \) strategies are strategic substitutes (complements).\(^4\) In our experimental treatments S+ and S- with \( \rho = 0.4 \), two completely mixed strategy equilibria exist.

\(^4\) If, in the equilibrium with \( \pi'' \), a player increases his contribution probability then the decisiveness \( q_i \) of all other players decreases. From Proposition 1(ii) follows that, then, all other players have an incentive not to contribute; vice versa for \( \pi' \).
Completely mixed strategy equilibria in our experimental treatments A with \((r_i)=(0.225, 0.25, 0.275, 0.3)\) and B with \((r_i)=(0.1, 0.2, 0.3, 0.4)\) are derived from the four equilibrium conditions described in Proposition 1 (i). In Treatment A with its moderately different \(c_i/G_i = r_i\) we find two completely mixed strategy equilibria. For the largely different \(r_i\) in Treatment B no completely mixed strategy equilibria exist. In all cases, there are possibly many pure/mixed strategy equilibria. All completely mixed or symmetric pure strategy equilibria of our experimental games are reported in Table 1. These are the most plausible candidates for equilibrium selection. ComplMix+ is selected by Harsanyi and Selten (1988), in the following HS. Diekmann (1993) suggests to select ComplMix+, if existent, also in the case of asymmetric games, i.e., for Treatment A. ComplMix-, if existent, is the second best of these equilibria and “Never contribute” (in S+, A, B; \(k>1\)) and “Always contribute” (S-; \(k<4\)) are the worst of these equilibria in terms of income. For \(k=4\) (\(k=1\) in S-) the vectors of expected incomes of ComplMix- and “Never contribute” (“Always contribute” in S-) are identical.

<table>
<thead>
<tr>
<th>Treat.</th>
<th>Equilibrium</th>
<th>(k=1)</th>
<th>(k=2)</th>
<th>(k=3)</th>
<th>(k=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S+</td>
<td>Compl.Mix+</td>
<td>.26</td>
<td>.46</td>
<td>.78</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>ComplMix-</td>
<td>-</td>
<td>.22</td>
<td>.54</td>
<td>.74</td>
</tr>
<tr>
<td></td>
<td>Never contr.</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S-</td>
<td>Compl.Mix+</td>
<td>0</td>
<td>.22</td>
<td>.54</td>
<td>.74</td>
</tr>
<tr>
<td></td>
<td>ComplMix-</td>
<td>.26</td>
<td>.46</td>
<td>0.78</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Always contr.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>A</td>
<td>Compl.Mix+</td>
<td>(.26,.33,.39,.44)</td>
<td>(.52,.59,.66,.74)</td>
<td>(.83,.87,.91,.96)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>ComplMix-</td>
<td>-</td>
<td>(.17,.13,.09,.04)</td>
<td>(.48,.41,.34,.26)</td>
<td>(.74,.67,.61,.56)</td>
</tr>
<tr>
<td></td>
<td>Never contr.</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>Compl.Mix+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>ComplMix-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Never contr.</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 1:** Theoretical contribution probabilities of all symmetric or completely mixed strategy equilibria of our experimental games with \(r=0.4\) in S+ and S-; \((r_i)=(0.225, 0.25, 0.275, 0.3)\) in A and \((r_i)=(0.1, 0.2, 0.3, 0.4)\) in B.

**Explanatory note:** For symmetric equilibria only the for all players identical contribution probability is reported, in asymmetric cases the vector of contribution probabilities for (player 1, player 2, player 3, player 4). Bold type means: selected by HS. “-“ indicates non-existence of the respective equilibrium. **ComplMix+, pos. frame:** For \(k=1\), determined by (5), if existent; for \(k=4\), \(p=1\); for \(k=2\) and 3 the Pareto-superior of the (if existent) two completely mixed strategy equilibria determined by the four equations from Proposition 1 (i), which are, in the cases of S+ and S-, equivalent to (6). **ComplMix-, pos. frame:** For \(k=1\), non-existent; for
k=4 determined by (4), if existent; for k=2 and 3 the Pareto-inferior of the (if existent) two completely mixed strategy equilibria determined by the four equations from Proposition 1 (i), which are, in the cases of S+ and S-, equivalent to (6). S+: For k, 1-p(5-k) with p(5-k) from S+.

The maximal number of equilibria is reported in Table 2. As an example take the case k=4 with the lowest maximum number of equilibria. There are two pure strategy equilibria (all or no one contributes) and there is (in treatments S+ and A) one completely mixed strategy equilibrium. There are no pure/mixed strategy equilibria in a symmetric Stag Hunt game because a pure strategy player, necessarily with \( p_i = 1 \), would earn less than the zero profit of the mixed strategy players. Because of the same reason, in an asymmetric game, no player with a cost/benefit ratio \( r_i \) would play \( p_i = 1 \) if a player with a cost/benefit ratio \( r_j < r_i \) plays a mixed strategy. Therefore, in asymmetric games, there is at most one equilibrium where the lowest cost player contributes with certainty and the others playing the mixed strategy according to case k=n with n=3, and there is at most one equilibrium where the two lowest cost players contribute with certainty and the other two playing the mixed strategy according to case k=n with n=2.

<table>
<thead>
<tr>
<th>Threshold k</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td># pure strategy equilibria</td>
<td>4</td>
<td>7</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td># completely mixed strategy equ.</td>
<td>( \leq 1 )</td>
<td>( \leq 2 )</td>
<td>( \leq 2 )</td>
<td>( \leq 1 )</td>
</tr>
<tr>
<td># pure/mixed strategy equilibria</td>
<td>( \leq 10 )</td>
<td>( \leq 24 )</td>
<td>( \leq 24 )</td>
<td>( \leq 2 )</td>
</tr>
</tbody>
</table>

**Table 2**: Number of equilibria in the positive frame.

### 3. Experiments

All our experimental games had n=4. Every player received an initial endowment (see Table 3). If at least k players contributed, then every player received a benefit of \( G_i \) Lab Dollars. In Treatment S+ (positive frame), players 1 and 3 with \((c_i, G_i) = (4,10)\) are called **small players**; players 2 and 4 with \((c_i, G_i) = (8,20)\) are called **large players**. All four players had the same \( r_i = c_i/G_i = 0.4 \). In Treatment S- (negative frame), \( G_i \) and \( c_i \) have the same absolute values as in Treatment S+ but are both negative. In Treatments A and B, every player received a benefit of \( G_i = 20 \) Lab Dollars. In Treatment A, contribution costs \( (c) \) are \((4.5, 5, 5.5, 6)\) Lab-Dollars and players thus have cost/benefit ratios \( (r) = (0.225, 0.25, 0.275, 0.3)\); in Treatment B costs are \((2, 4, 6, 8)\) Lab-Dollars and cost/benefit ratios \((0.1, 0.2, 0.3, 0.4)\). The (cost, benefit) combination of a player defined
his type. A player kept his type during the whole experiment. Every subject participated in only one treatment but in four experiments with k=1,2,3,4.

Note that the endowment has no strategic significance; only the expected income differences with and without contributing have. In order not to lead subjects astray (by making them think about the meaning of individually different endowments), we gave all players in a game the same endowment. The endowment serves mainly to guarantee non-negative income in the worst case scenarios. Given the costs and benefits in S+ and S-, this implies a necessary endowment of 8 lab dollars in S+ and 20 in S-. A consequence is that, although the games with threshold k in S+ and with threshold 5-k in S- are strategically equivalent, only the large players have the same payoffs when all players play equivalent strategies. For the small players in S-, an endowment of 14 lab dollars would have implied equal payoffs. Thus, small players in S- get a lump sum transfer of 6 lab dollars compared with their counterparts in S-. This is the price for the equal endowments. It turned out that small as well as large players played (about) equal strategies within and between treatments S- and S+.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Endowment</th>
<th>costs $c_i$</th>
<th>Benefits $G_i$</th>
<th>$c_i/G_i$</th>
<th>#sessions (at V, at TU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S+</td>
<td>8</td>
<td>(4,8,4,8)</td>
<td>(10,20,10,20)</td>
<td>0.4</td>
<td>(10, -)</td>
</tr>
<tr>
<td>S-</td>
<td>20</td>
<td>(-4,-8,-4,-8)</td>
<td>(-10,-20,-10,-20)</td>
<td>0.4</td>
<td>(10, -)</td>
</tr>
<tr>
<td>A</td>
<td>8</td>
<td>(4.5, 5, 5.5, 6)</td>
<td>20</td>
<td>(.225, .25, .275, .3)</td>
<td>(6, 12)</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
<td>(2, 4, 6, 8)</td>
<td>20</td>
<td>(.1, .2, .3, .4)</td>
<td>(10, 6)</td>
</tr>
</tbody>
</table>

**Table 3:** Game parameters (in lab dollars) in the four treatments for players i=1,2,3,4 and number of sessions with eight subjects either at TU (Technische Universität Berlin) or V (Europa-Universität Viadrina Frankfurt (Oder)).

Our research questions justify the investigations of S+, S- and an asymmetric treatment. But do we really need both asymmetric treatments A and B? In order to derive theoretical predictions as for S+ and S-, the differences between cost/benefit ratios of the players have to be rather small, i.e., A is necessary. Such small differences, however, invite criticism that the true effect of asymmetries is overlooked. It might be that, for large enough differences, pure strategies are played, namely that exactly the k least cost players contribute. As we will see in the results section, this expectation is false. For A and B, we find qualitatively identical results concerning contribution frequencies depending on thresholds and costs. The dependence on costs is clearer for B, however.
In order not to blow up the number of our main questions and results, we neglect the “minor results” from explicitly comparing behavior in A and B.

We conducted computerized laboratory experiments (implemented with z-tree, Fischbacher, 2007) with 8 subjects per session (432 subjects altogether) who were randomly assigned to a player type. In the “symmetric” Treatments S+ and S-, in every session there were four small and four large players. In Treatments A and B, in every session there were two players of each type. Players participated in 32 games played in 32 periods. In every period, the eight subjects were randomly allocated to two groups with the restriction that the groups consisted of two small and two large players (Treatments S+ and S-) or of exactly one player of each type (Treatments A and B). Always after eight games the threshold k changed. In different sessions, all thresholds were adopted in different orders but with the restriction that, across the sessions, each k was played about the same times first, second, third, and fourth. Subjects were not informed about the order of the thresholds in the beginning, but only when the threshold was changed. As described above we used a stranger design, i.e., the composition of the groups was changed after each round and the co-players could not be identified. Subjects were informed about how many players contributed to the public good but not who contributed. Hence, players were unable to build a reputation. Most experiments took place in the laboratory of the Viadrina University in Frankfurt (Oder), but 18 of the 54 sessions were carried out in the laboratory of Technische Universität Berlin. (See Table 3.) We find a small subject pool effect.

Before subjects played the BTPG games, they were given printed instructions and had the possibility to ask questions. Instructions contained general information, the description of the threshold public good game and two example calculations (see Appendix C). Furthermore, they had to answer five on-screen comprehension questions to make sure that everyone understood the game. The experiment did not start before all subjects had answered the questions correctly. In cases of problems, personal advice was given. In every period, the subjects were reminded of the actual threshold and, every 8th period, the changing of the threshold was announced. In each period subjects were informed in the decision screen that the group composition had been changed and they were required to decide whether or not to contribute. In the profit display screen, they were informed about the number of contributing players and whether the threshold was reached. They further received information about their payoff in the current period.
For each lab dollar earned, subjects were paid 4 Eurocents. After the experiment, subjects were presented three incentivized questions testing their understanding of probability calculus. For each correctly answered question (on average two), the subject was paid one additional Euro. Participants earned between 14 and 33 Euros with an average of 23.29 Euros. Sessions lasted roughly 45 minutes.

4. Hypotheses

Every player plays games with eight repetitions in a stranger design and is characterized by his individual contribution frequency $ICF$, a number between 0 and 8. Aggregate behavior of players of type $i$ (defined by costs and benefits) in a game with threshold $k$ can be characterized by frequency distributions $f_i(ICF, k)$ or, more aggregated, by the average contribution frequencies $ACF_i(k)$. We will investigate four main hypotheses.

**Invariances:** Players’ aggregate behavior is neither affected by the frame of the game nor by the scale (magnitude) of players.

(H1) In Treatments S+ and S-, players of type i (small or large players) have the same cost/benefit ratio and therefore the same (a) $ACF_i(k)$ and (b) $f_i(ICF, k)$.

(H2) If $ACF_i^+(k)$ and $f_i^+(ICF, k)$ apply for S+ and $ACF_i^-(k)$ and $f_i^-(ICF, k)$ for S- then (a) $ACF_i^+(k) = 1 - ACF_i^-(n - k + 1)$ and (b) $f_i^+(ICF, k) = 8 - f_i^-(ICF, n - k + 1)$.

(H1) is motivated by Proposition 1 and (H2) by the Strategically Neutral Transformation (see above).

**Equilibrium Selection:** For treatments S+, S-, and A, the Pareto-dominant of the symmetric or completely mixed strategy equilibria is selected.

This plausible equilibrium selection has been proposed by HS for symmetric games and by Diekmann (1985, 1993) for symmetric and asymmetric Volunteer’s Dilemma games. We will see that the predicted probabilities are more or less different from the empirical frequencies which may be explained, for example, by social preferences. Therefore, we will test also qualitative predictions from this selection.

(H3) In Treatment A, $c_i < c_j$ implies $ACF_i(k) < ACF_j(k)$.

(H4) In Treatments A, S+, and S-, $ACF_i(k)$ increase with $k$. 

15
(H5) For k=1 in S-, $p_i = 0$ is the most frequent choice; for k=4 in S+, A, and B, it is $p_i = 1$.

Although (H3) and (H4) are not suggested to apply for treatment B, where no completely mixed strategy equilibria exist, we will test them also for B.

A more general question is whether a unique equilibrium selection theory, even after the introduction of average social preferences, or any other hypothesis with homogeneous (average) players can apply at all.

**Homogenous players:** Every player of type i (same costs and benefits) contributes with the same probability $p_i$.

(H6) All $f_i(ICF, k)$ are binomial distributions.

We further want to control for dynamic influences. This is routinely done by including a term for the period (1-32) or round of a repeated game (1-8) in a regression analysis. The investigation of a more specific dynamic influence is inspired by findings of Erev and Rapoport (1990), Chen et al. (1996), and McEvoy (2010) in sequential BTPG games. In a sequential game a *non-pivot player* is a player whose contribution cannot determine the reaching of the threshold (because there are already k contributions or because k cannot be reached by the remaining players). All other players are *pivot-players* and they contributed with higher frequency than non-pivot-players. A *pivot player* in our repeated games is defined as a player who is informed that, in the previous round, k-1 of the other players have contributed. Otherwise a player is called a *non-pivot player*. This definition is independent of the player’s own behavior. Either no player is a pivot player or all contributing players are pivot players or all non-contributing players are. Although our experiments are with a stranger design, i.e., in every round the group of n players is randomly selected from a larger set of players, we will test the following hypothesis.

**Dynamics.** Pivot players increase (decrease) their contribution probability in the next round of a positively (negatively) framed game.

(H7) Pivot players contribute with a higher (lower) probability in S+, A, B (S-) than non-pivot players.

Finally, we will conduct tests in order to detect or exclude differences between the behavior of subjects in our two laboratories in Berlin and Frankfurt (Oder).
5. Results

In this section we will present results, mostly with respect to the above hypotheses. A thorough discussion of these results is provided in Section 6.

5.1 Average and individual contribution frequencies

In Tables 4, 5, and 6 average contribution frequencies $ACFs$ are reported. Tests are carried out with respect to our hypotheses.

Concerning our invariance hypotheses, we find systematic but mostly rather small effects in Table 4. Large players’ average contribution frequencies in S+ (S-) are higher (lower) for all thresholds, but only by 0.04 (0.09). Only two of the eight differences are significant. Players’ contribution frequencies in the positive frame are higher than the transformed frequencies in the negative frame for every threshold and small and large players, but only by 0.05 on average. None of the eight differences is significant. Neither are players in the positive frame significantly more or less successful in producing the public good than players in the negative frame in preventing the production of the public bad.

<table>
<thead>
<tr>
<th>k</th>
<th>SmPl</th>
<th>LaPl</th>
<th>HS</th>
<th>prod*(k)</th>
<th>SmPl</th>
<th>LaPl</th>
<th>HS</th>
<th>prod*(k)</th>
<th>1-prod*(5-k)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.35*</td>
<td>0.37*</td>
<td>0.26</td>
<td>0.85</td>
<td>0.30</td>
<td>0.26</td>
<td>0</td>
<td>0.48</td>
<td>0.83</td>
</tr>
<tr>
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<td>0.56</td>
<td>0.46</td>
<td>0.75</td>
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<td>0.39</td>
<td>0.22</td>
<td>0.51</td>
<td>0.64</td>
</tr>
<tr>
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<td>0.63*</td>
<td>0.78</td>
<td>0.53</td>
<td>0.57*</td>
<td>0.49*</td>
<td>0.54</td>
<td>0.36</td>
<td>0.49</td>
</tr>
<tr>
<td>4</td>
<td>0.74§</td>
<td>0.81</td>
<td>1</td>
<td>0.45</td>
<td>0.75§</td>
<td>0.59</td>
<td>0.74</td>
<td>0.18</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Table 4: Average contribution frequencies $ACF$ in Treatments $S+$ (positive frame) and $S-$ (negative frame), theoretical contribution probabilities ComplMix+, denoted as $HS$, and prod=frequency of production of the public good (bad). Small player type SmPl with $(G_{S,cS})=(10,4)$ and large player type LaPl with $(G_{L,cL})=(20,8)$. $k=$ threshold.

Explanatory notes. All tests are two-sided, at the 5% level, and based on averages in 10 sessions. Small vs. large players: $^§$ Significant in Wilcoxon matched pairs-tests. k (position of *) vs. k+1: * Significant in Wilcoxon matched-pairs test. (6 of 8 tests for k vs. k+2 are significant). S+ vs. S-: No significant differences in Wilcoxon tests between $ACF_i^+(k)$ and $1 - ACF_i^-(n - k + 1)$ as well as between prod*(k)and 1- prod*(5-k).

Result 1 (H1 mostly confirmed, no strong scaling effects, except for k=4). According to Table 4, H1(a) is rejected for k=4 in both treatments; it is not rejected for other thresholds.
Result 2 (H2 confirmed, only small differences between positive and negative frame): According to Table 4, $ACF_i^+(k) = 1 - ACF_i^-(n - k + 1)$ is not rejected in any of the eight comparisons. Frequency of production of the public good in the positive frame $= prod^*(k) = 1-prod^*(5-k)$ is not rejected in four comparisons.

The results in the asymmetric treatments are presented in Tables 5 and 6 and Figure 1. With respect to equilibrium selection and its consequences H3, H4, and H5, our first observation is that some ACPs in Tables 4 and 5 are close to the predicted values while others show larger differences. The general rejection of ComplMix+ as a description of behavior is implied by Result 6. It is remarkable that, in Tables 5 and 6, we find the same pattern of significant differences in A and B. The contribution probabilities of the least-costs players are always significantly higher than those of the highest-costs players.

<table>
<thead>
<tr>
<th>c/Gi</th>
<th>0.225</th>
<th>0.25</th>
<th>0.275</th>
<th>0.3</th>
<th>ComplMix+</th>
<th>prod</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.225</td>
<td>0.25</td>
<td>0.275</td>
<td>0.3</td>
<td>0.225</td>
<td>0.25</td>
</tr>
<tr>
<td>k</td>
<td>0.389</td>
<td>0.497</td>
<td>0.333*</td>
<td>0.250*</td>
<td>0.26</td>
<td>0.33</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.39</td>
<td>0.44</td>
</tr>
<tr>
<td>2</td>
<td>0.622</td>
<td>0.625</td>
<td>0.483*</td>
<td>0.483</td>
<td>0.52</td>
<td>0.59</td>
</tr>
<tr>
<td>3</td>
<td>0.733</td>
<td>0.792</td>
<td>0.733§</td>
<td>0.559§</td>
<td>0.83</td>
<td>0.87</td>
</tr>
<tr>
<td>4</td>
<td>0.997</td>
<td>0.948</td>
<td>0.931</td>
<td>0.944*</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5: Average contribution frequencies of the four player types in Treatment A ($A_{TU} + A_V$).

Explanatory notes. All tests are two-sided, at the 5% level, and based on averages in 6 sessions at V and 12 sessions at TU. V vs. TU: Four differences are significant (bold types) in Wilcoxon tests, three higher probabilities in TU, one in V. k vs. k+1: 9 of the 12 differences are significant in Wilcoxon matched-pairs tests. (except k=2, c/Gi =0.25, k=2, c/Gi =0.3). All differences between k and k+2 are significant. Player types: * (§) Significant differences between player types compared to the type with c/Gi =0.225 (0.25) in Wilcoxon tests.

<table>
<thead>
<tr>
<th>c/Gi</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>prod</th>
</tr>
</thead>
<tbody>
<tr>
<td>k</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.676</td>
<td>0.344*</td>
<td>0.227*</td>
<td>0.277*</td>
<td>0.90</td>
</tr>
<tr>
<td>2</td>
<td>0.781</td>
<td>0.613</td>
<td>0.398*</td>
<td>0.418*</td>
<td>0.79</td>
</tr>
<tr>
<td>3</td>
<td>0.930</td>
<td>0.840</td>
<td>0.688*§</td>
<td>0.637*§</td>
<td>0.81</td>
</tr>
<tr>
<td>4</td>
<td>0.984</td>
<td>0.945</td>
<td>0.918</td>
<td>0.883*</td>
<td>0.78</td>
</tr>
</tbody>
</table>

Table 6: Average contribution frequencies of the four player types in Exp B ($B_{TU} + B_V$) and frequency of production of the public good (prod).

Explanatory note. Tests are two-sided, at the 5% level, and based on averages in 10 sessions at V and 6 sessions at TU. V vs. TU: No significant differences in Wilcoxon tests. k vs. k+1: All differences are significant in Wilcoxon matched-pairs tests (except k=1, c/Gi =0.1). Player types: * (§) Significant differences compared to the type with c/Gi =0.1 (0.2) in Wilcoxon tests.
**Result 3** (H3 rejected, **qualitative efficiency**): In treatments A and B, players with lower costs contribute more (see Tables 5 and 6: in both treatments not less frequent contributions in 20 and significantly more in 10 of the 24 possible comparisons).

**Result 4** (H4 confirmed, **necessary adaptations to meet the threshold**): In all treatments, **ACFs increase with the threshold k**. For the transition from k to k+1, the difference is significant in 6 of 12 tests in S+ and S- (Table 4) and in 21 of 24 tests in treatments A and B (Tables 5 and 6).

In S+, Result 4 describes an attempt to meet the increasing threshold, which is apparently stronger than the fear to waste one’s contribution because others do not cooperate. In S-, lower k make the players more reluctant to contribute and enjoy the negative costs. Results 3 and 4 are illustrated rather clearly in Figure 1.

**Result 5** (H5 confirmed, **payoff dominance is a better predictor than risk dominance**): For k=4 (k=1 in S-), neither the predictions of payoff dominance (PD) nor those of risk dominance (RD) apply (no statistical test for contribution probabilities = 1 or 0), but at least the empirical probabilities (averages over small and large players: 28% in S-, 72% in S+, 96% in A, 93% in B) are closer to PD than to RD, i.e., to 0 in S- and to 1 in S+, A, and B.

---

**Figure 1:** Average contribution frequencies in Exp B with thresholds k and cost/benefit ratios $r = c/G$ (graphical representation of Table 6).
**Result S (Subject pool):** In Treatment B (Table 6), no significant differences between V and TU subjects are found when comparing the ACFs of a certain player type in a game with a certain threshold, i.e., in 16 tests at the 5% level. In Exp A (Table 5) four significant differences are found.

Every decision situation occurs 8 times so that every subject can contribute to the public good (for every threshold) between 0 and 8 times. We call this number the *individual contribution frequency (ICF)*. The distributions of ICFs are provided in Appendix C for every player type in every experiment. The ICF distributions are used for second tests of H1 and H2 (see Appendix B), but the *central question* tackled with ICFs is whether theories with unique equilibrium selection can apply.

![Figure 2: Frequency distribution of individual contribution frequencies (ICFs) of all players in Treatment S+ (Table A1 in Appendix C, aggregated over small and large players). k= threshold. For every k, 8 decisions by 80 individuals.](image1.png)

![Figure 3: Frequency distribution of individual contribution frequencies (ICFs) of all players in Treatment S- (Table A1 in Appendix C, aggregated over small and large players). k= threshold. For every k, 8 decisions by 80 individuals.](image2.png)
In Figures 2 and 3, the distributions of ICFs in treatments S+ and S- are presented (aggregations over small and large player types). The individuals with 0 or 8 contributions can be assumed to play a pure strategy or to use mixture probabilities close to 0 or 1. According to this criterion, every third subject in S+ (35.0%) and S- (31.6%) plays a pure or almost pure strategy; in A (53.5%) and in B (50.5%) even every second subject does. This is a first indication that players of the same type use different strategies. The alternative to this hypothesis is that players of the same type play the same mixed strategy. If all decisions are independent (implied by equilibrium play), then the ICFs of the same player type are distributed binomially.

**Result 6:** For every game, every player type, and every threshold (except two cases of the Stag Hunt game) the hypothesis of a **binomial distribution of ICFs is significantly rejected**.

The eight distributions in Figures 2 and 3 are certainly not binomial distributions, not even in the Stag Hunt games k=4 in Figure 2 and k=1 in Figure 3. The hypothesis that these distributions are binomial distribution is rejected in chi-square tests with extremely small p-values (p<10^{-12}). We get similar results\(^5\) for the 32 (two treatments, four thresholds, four player types) distributions of ICFs in Treatments A and B.

### 5.2 Regression analysis

The following regression analysis (Tables 7 and 8) provides support of our previous results, but also serves to investigate dynamics of behavior. In particular, we introduce the dummy variable PivotPl (= 1 if k-1 of the other players contributed in the previous period, = 0 otherwise) because Erev and Rapoport (1990), Chen et al. (1996), and McEvoy (2010) found that, in sequential games, the potential or real pivotality of players increases the contribution frequency in the positive frame (see Section 4). Moreover, if the other three players in a Stag Hunt game (StH) have contributed, this is not only a signal for the general reliability of others but it involves also a moral obligation to make the necessary fourth contribution. Therefore, we introduce also variables PivotPl x StH and Period x StH, where StH is 1 if k=1 in S- or k=4 in the other treatments and 0 otherwise. In the following interpretation of the regression results we rely on the BIC

\(^5\) Because we have to distinguish four types of players, the ICFs are smaller than in Figures 1 and 2. Therefore, for chi-square tests, we unite classes so that four classes remain: {ICF=8}, {ICF=6,7}, {ICF=3,4,5}, {ICF=0,1,2}. The 32 chi-square tests with these classes resulted in deviations with extremely high significance levels, except two cases of the Stag Hunt game, one with p=0.9999 (35 of 36 subjects have ICF=8 and one subject has ICF=7) and one with p=0.02.
minimizing variable structure. Stylized results of our regression analysis are, first, confirmations of previous results.

<table>
<thead>
<tr>
<th>Variable</th>
<th>S+</th>
<th>S-</th>
<th>S+</th>
<th>S-</th>
<th>S+</th>
<th>S-</th>
<th>S+</th>
<th>S-</th>
</tr>
</thead>
<tbody>
<tr>
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<td>-1.33***</td>
<td>-0.17</td>
<td>-1.42***</td>
<td>-0.05</td>
<td>-1.31***</td>
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<tr>
<td></td>
<td>(0.28)</td>
<td>(0.26)</td>
<td>(0.29)</td>
<td>(0.27)</td>
<td>(0.29)</td>
<td>(0.25)</td>
<td>(0.29)</td>
<td>(0.27)</td>
</tr>
<tr>
<td>PivotPl</td>
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<td>0.93***</td>
<td>-1.01***</td>
<td>0.77***</td>
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<td>0.81***</td>
<td>-0.67***</td>
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<tr>
<td></td>
<td>(0.12)</td>
<td>(0.10)</td>
<td>(0.12)</td>
<td>(0.12)</td>
<td>(0.13)</td>
<td>(0.12)</td>
<td>(0.13)</td>
<td>(0.12)</td>
</tr>
<tr>
<td>LargePlayer</td>
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<td>0.22</td>
<td>-0.28</td>
<td>0.23</td>
<td>-0.31</td>
<td>0.22</td>
<td>-0.31</td>
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<tr>
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<td>(0.22)</td>
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<td>(0.21)</td>
<td>(0.22)</td>
<td>(0.21)</td>
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<td>0.38***</td>
<td>0.41***</td>
<td>0.31***</td>
<td>0.36***</td>
<td>0.38***</td>
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<tr>
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<td>(0.08)</td>
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<td>(0.07)</td>
<td>(0.08)</td>
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<tr>
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<td>0.01</td>
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<td>0.01</td>
<td>-0.014</td>
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<td>-0.015*</td>
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Table 7: Logit-Regression of contribution decisions in treatments S+ and S- with standard errors (clustered with respect to subjects) in parentheses.

Explanatory notes: *(**,*** ) - significant at 5%(1%,0.1%)-level. In S+ (S-). StH is 1 for k=4 (k=1) and 0 otherwise. PivotPl is 1 if k-1 contributions by other players in previous period and 0 otherwise. Periods=2-8, 10-16, 18-24, 26-32.

**Result 1**: The dummy for the large player is insignificant.

The absolute coefficients of PivotPlayer, and Threshold k for S+ and S- (Table 7) are quite similar: they are not significantly different in t-tests at the 5% level. For the Stag Hunt game, there seem to be differences concerning pivot player behavior, because the coefficients for PivotPl x StH are significantly different. Nonetheless, we state:

**Result 2**: The “mirror image” character of Treatments S+ and S- is supported.

In Table 8, we find (5 of 6) negative dummies for the contributions of the higher cost players; in the case of treatment B, all dummies are significant, in treatment A only player 4 contributes significantly less than player 1.

**Result 3**: In treatments A and B, the higher cost players contribute less frequent than the least cost player 1.

**Result 4**: In all treatments, the higher the threshold, the more frequent are contributions.
In addition, the regression analysis provides new insights concerning dynamic behavior. Relying on the regressions with the minimal BIC values there is no significant trend. All dynamics stem from the influence of PivotPlayer which is significant in all treatments.

**Result 7:** Contributing is more (less in S-) probable if a player has been pivotal in the last period. This effect is particularly strong in Stag Hunt games.

**Result 8:** With the BIC minimizing variable structure we observe no trend in the contribution decisions.

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**Table 8:** Logit-Regression of contribution decisions in treatments A and B with standard errors (clustered with respect to subjects) in parentheses.

Explanatory notes: *(**,***,***) - significant at 5%(1%,0.1%)-level. In S+ (S-) StH is 1 for k=4 (k=1) and 0 otherwise. PivotPl is 1 if k-1 contributions by other players in previous period and 0 otherwise. Periods=2-8, 10-16, 18-24, 26-32.

Differences in the behavior of our two subject pools (Table 5) did not cause a significant dummy “Pool V” because these differences were not unidirectional.
Result S': There is no subject pool effect.

Moreover, we conducted several alternative regressions to control for various influences. We used sex and field of study and answers to incentivized questions about probability calculus as controls and we used the rounds (from 1 to 8) within a threshold level. We alternatively also conducted all regressions with an autoregressive term. None of these variations change the outcome of the analysis.

5. Discussion and Conclusion

Our investigation is based on a large data set with 16 rather different games. This allows us to characterize behavior in BTPG games under several aspects (see Table 8) and, we think, without the danger that the results are driven by a special selection of experimental parameters. To the best of our knowledge, results 1, 2, 4, and 6 are completely new in the field of BTPG games; result 7 is new for simultaneous games. Results 1 and 2 confirm theory and are surprising on the background of the many framing effects which Experimental Economics report. Results 2 and 8 contradict the only investigation (Sonnemans et al., 1998) concerned with these topics. Result 3 confirms and extends findings in the literature on the Volunteer’s Dilemma to games with higher thresholds. Result 5 is another strong argument in favor of payoff dominance, in a situation without clear evidence in the literature.

Results 1 and 2 cannot completely exclude scaling and framing effects but show that such effects are rather weak. They confirm theory and are surprising because we regularly observe different behavior in strategically equivalent games or, within games, by strategically equivalent players. The lacking or weak scaling effect is counter to fairness considerations when fairness means mainly equality. Proposition 1 (iii) shows that, in a mixed strategy equilibrium of S+ (S-), large (small) players have a higher expected profit.

Changing the signs of all costs and benefits from positive to negative leads to a strategically equivalent game where essentially “contributing” and “non-contributing” are exchanged. There are many examples of linear Public Good games (positive frame) and Common Pool games (negative frame) with significantly different behavior (e.g. Andreoni, 1995, Willinger and Ziegelmeyer, 1999; Park, 2000; Dufwenberg et al., 2011), but one
should keep in mind that linear Public Good/Common Pool games with their unique (worst outcome) equilibrium are strategically completely different from BTPG games with their plethora of equilibria. In linear Public Good games, players seek cooperation through non-equilibrium play; in BTPG games they have a lot of more or less cooperative equilibria at their disposal. Sonnemans et al. (1998) is, to the best of our knowledge, the only BTPG experiment where players contribute under a positive and under a negative frame. In the course of repetitions of games they find, in the negative frame, a trend towards less cooperation while we find no primary trend, but a reaction to a Pivot Player status which appears as a trend towards more cooperation (in the positive as well as in the negative frame) if we do not control for this type of behavior. The main difference between the experiments is that Sonnemans et al. (1998) investigate 20 rounds with a partner design while we have eight rounds with a stranger design (i.e., a new random selection of groups in every round). In addition, their experiment has only one threshold, namely k=3 of n=5, while we investigate k=1,2,3,4 of n=4.

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<tr>
<td>4 necessity</td>
<td>theory confirmed*: higher thresholds cause more contributions</td>
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<td>5 payoff dom. (PD)</td>
<td>PD better than RD: in Stag Hunt games, up to 96% contribute</td>
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<td>Homogeneity</td>
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<td>6 individual diversity</td>
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<td>7 pivot player behavior</td>
<td>confirmed: more contributions after pivot player status</td>
</tr>
<tr>
<td>8 trend</td>
<td>rejected: not more or less contributions over 32 periods</td>
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Table 8: Compilation of stylized results. * Qualitative hypothesis from numerical results of the selected equilibrium ComplMix+ (Table 1). PD= pay-off dominance, RD= risk dominance.

Our third result (lower costs - higher contribution frequency) confirms results from Volunteer’s Dilemma experiments (Diekmann, 1993; Franzen, 1995) and extends them to other thresholds. This result seems to contradict theoretical predictions which, however, crucially rely on egoistic preferences and on unique equilibrium selection. Predictions
change with the introduction of altruism/warm glow (Bolle, 2017). A related explanation is efficiency concerns (Przepiorka and Diekmann, 2013, and Diekmann and Przepiorka, 2015, for the Volunteer’s Dilemma, and Bolle, 2017, for all thresholds).

Results 4 (higher threshold – higher contribution frequency) and 5 (payoff dominance) show that the subjects are “optimistic” about the contributions of others. While evidence from the literature is mixed, the results in our four Stag Hunt games are far closer to payoff dominance than to risk dominance. For k<n, we have no such concept and there are no results from previous experiments about contribution frequencies depending on the threshold. If we take the Pareto superior of the completely mixed strategy equilibria of game A as a benchmark, then contribution frequencies should increase with the threshold. Players should be optimistic but (except in the Stag Hunt game) not too optimistic about the contribution of others. With increasing thresholds, they feel an increasing necessity to contribute. This hypothesis is confirmed in our experiments.

For theoretical predictions, we select the payoff dominant equilibrium from the set of symmetric or completely mixed equilibria. This selection is proposed by Harsanyi and Selten (1988) for S+ and S- and by Diekmann (1993) for asymmetric Volunteer’s Dilemma games. This principle is not applicable for most cases in treatment B because, there, the set of completely mixed strategy equilibria is empty (Table 1). Although some average contribution frequencies in S+, S-, and A are close to the contribution probabilities of the selected equilibria, the selection of a unique equilibrium or non-equilibrium mode of play is generally rejected (Result 6): Behavior cannot be described by homogenous players. This rejection concerns also Quantal Response Equilibria which are suggested by Goeree and Holt (2005) for BTPG games.

The last two results report attempts to identify dynamic behavior in our games with eight repetitions in a stranger design. In a regression analysis, a weak trend towards more cooperation is found only with a suboptimal structure of variables. If the BIC minimizing variables PivotPl and PivotPl x StH are introduced, the influence of trend is no longer significant. Pivotality of player i means that, in the previous period, k-1 of i’s co-players had contributed and therefore player i’s decision had been crucial for the outcome. Related findings in the literature stem from experiments with sequential contributions where pivotality means that, without a player’s contribution, k cannot or might not be reached. The difference is that, with sequential contributions, players know when they
are or could be pivotal while, with several rounds of a simultaneous move game, players experience to be pivotal and seem to believe that, even in a stranger design, i.e., with new co-players, there is an increased probability of being pivotal also in the next round. On the first glance such behavior seems to be rather naïve, but if we assume such players to believe that their co-players play mixed strategies with unknown contribution probabilities, then their behavior can be interpreted as a reaction to a signal they receive.

We employed a stranger design with a non-negligible probability of meeting one or more co-players in the following rounds. This setup was constant over all games. Thus we do not claim that we have any results about the differentiation between partner and stranger design. Nor do we have any results concerning the number of players which was four in all our games.

Altogether, our results confirm theoretical predictions to a greater extent than most other experimental investigation of games. We think that the large variety of equilibria may be one of the reasons for this phenomenon. It allows more cooperative oriented or more competition or more exploitation oriented subjects to play “their” equilibrium. This explanation implies individual diversity of behavior which has been proposed also by Fehr and Schmidt (1999), Engelmann and Strobel (2004), Fischbacher et al. (2001), and Bolle et al. (2012). In addition to these finite mixtures of individual modes of play (possibly described by individual preferences or beliefs), many authors assume continuous mixtures of preferences or behavior.

BTPG is an important class of games with many applications, such as forming teams for producing a public good or preventing a public bad. Other important applications are democratic decisions in parliaments, international organizations, committees, and assemblies of shareholders. Our research closed gaps in the literature by deriving many clear behavioral regularities from our experimental data. Thus, our study may guide a theory of behavior in BTPG games and beyond (Bolle, 2017). For behavioral theories derived from independent principles, meeting our detailed description of behavior is a major challenge.

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6 Bolle and Otto (2016) propose a dependency of social preferences of a player (determining his mode of play) on the strategic situation, here defined by k and all costs and benefits (the player types).
References


Appendix

A. Theoretical issues

Proof of the **strategically neutral transformation**: The pay-off of a player in an BTPG game is $R_i = Q(k)G_i - p_i c_i$ with $p_i$ describing i’s pure or mixed strategy and $Q(k)$ denoting the probability that there are at least $k$ contributions. Let us assume that costs and benefits are negative. We now re-arrange terms:

$$R_i = (1 - (1 - Q(k))G_i - (1 - (1 - p_i)c_i = G_i - c_i + (1 - Q(k))(-G_i) - (1 - p_i)(-c_i).$$

$p_i’ = 1 - p_i$ describes the probability of the strategy non-contributing, $Q(k)’ = 1 - Q(k)$ describes the success probability for the event “threshold $k$ is not reached”, i.e., that there are less than $k$ contributions or at least $n+1-k$ non-contributions. Therefore $R_i$ describes the pay-off of a BTPG game with costs $-c_i$, benefits $-G_i$, the action “non-contributing” instead of “contributing”, and the success probability for $n+1-k$ non-contributions. The only difference to a BTPG game as defined in Section 2 is the strategically irrelevant lump-sum transfer $G_i - c_i$ which can be manipulated in experiments as an unconditional endowment.

Definition of **Risk dominance according to HS**: For the question of whether a mixed or pure strategy equilibrium $p$ risk dominates another equilibrium $p’$ first the bicentric prior of $p$ and $p’$ is derived. For BTPG games we have to determine, for every $0 \leq t \leq 1$, whether $a_i = 1$ (contribute) or $a_i = 0$ (do not contribute) is a best response of player i to the other players contributing according to the t-mixture of $p_{-i} = (p_1, ..., p_{i-1}, p_{i+1}, ..., p_n)$ and $p’$, i.e., with probabilities $t * p_{-i} + (1 - t) * p’_{-i}$. The shares of $t$ with $a_i = 1$ constitute a vector $x$ of prior probabilities. With these priors the *tracing procedure* is carried out where for every $0 \leq t’ \leq 1$ equilibria are determined in a game where player i assumes that, with probability $t’$, the BTPG game is played and with $1 - t’$ the other players decide according to the prior probability. If there is a continuous path of equilibria from $t’=0$ to $t’=1$ then the corresponding equilibrium for $t’=1$ is selected.

**Proposition 2**: In the case $k=n$, if $r_i > \prod_{j \neq i}(1 - (r_j)\frac{1}{n-1})$ for all $i$ then $(0, ..., 0)$ risk dominates all other equilibria.

**Proof**: The t-mixture of $(1, ..., 1)$ and $(0, ..., 0)$ is $(t, ..., t)$ and the best response of player i to this strategy is 1 if $q_i = t^{n-1} \geq r_i$ (Proposition 1). Therefore the bicentric priors of the
equilibria \((1, ..., 1)\) and \((0, ..., 0)\) are \((x_i^*) = (1 - (r_i)^{1/n-1})\). Because of \(q_i = \prod_{j \neq i} x_j^*\) the best response to these priors is \(p_i = 0\) (Proposition 1). Substituting \((1, ..., 1)\) by any other equilibrium the priors are necessarily smaller and again the best response to these priors is \((0, ..., 0)\). As \((0, ..., 0)\) is an equilibrium also of the BTPG game, there is a constant path of equilibria \((0, ..., 0)\) for all \(t\) which constitutes the generically unique risk dominant equilibrium (Lemma 4.17.7 in Harsanyi and Selten, 1988).

B Testing invariance with ICFs

We test H1 and H2 again under the assumption of independent decisions.

**Result 1'**: *Players in the same frame with the same cost/benefit ratio show the same distribution of ICFs.* (H1) (b) is not rejected.

We test (H1) (b) by comparing the ICFs of small and large players (from all periods, i.e., the frequencies from Table A1 in Appendix C) in chi-square tests, separately and jointly for \(k=1,2,3,4\). In the joint test, in \(S^+\) we get \(\chi^2 = 30.2\) (df=31\(^7\), \(p=0.508\)), in \(S^-\) we get \(\chi^2 = 32.8\) (df=32, \(p=0.427\)). The \(p\) values in the eight tests with single \(k\) are similar, all are above 0.05.

**Result 2'**: *Behavior in the negative frame \(S^-\) is equal to the “mirrored” behavior of that in the positive frame \(S^+\).* (H2) (b) is not rejected.

Comparing Figures 2 and 3 in Section 5.1, we notice that the frequency of \(ICF=8\) in Treatment \(S^+\) with the threshold \(k=4\) meets that of \(ICF=0\) in Treatment \(S^-\) with the threshold \(k=1\). If behaviors in Treatments 1 and 2 are completely mirrored, we should find these similarities also for other ICFs. A chi-square test \((\chi^2 = 34.4, \text{df}=32, p=0.35)\) of this hypothesis, based on the frequencies in Figures 2 and 3 (Table A1), does not indicate significant differences. Also the four tests for \(k=1, 2, 3, 4\) are insignificant with \(p > 0.05\).

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\(^7\) There are 8x9 classes, 8x8 of them independent. For every class, the average ICF of the two small and the two large players are computed as the hypothetical joint ICF. One average ICF \((k=1, ICF=6)\) has zero contributions. This class is united (for \(S^+\) as well as for \(S^-\)) with a neighboring class. Therefore, we get df=64-2-31=31.
C. Data

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</tr>
<tr>
<td>2</td>
<td>5 2 3 9 3 5 2 1 6</td>
</tr>
<tr>
<td>3</td>
<td>1 1 1 3 5 3 4 4 14</td>
</tr>
<tr>
<td>4</td>
<td>1 1 0 0 0 0 2 1 31</td>
</tr>
</tbody>
</table>

**Table A1**: Frequency distribution of ICF in Treatments S+ and S-. For every game and every player type 40 players (=number of ICF=sum of rows).

**Table A2**: Frequency distribution of ICF in Treatment A. For every game and every player type 8 decisions by 36 subjects (=number of ICF=sum of rows).
Player type 1: \( r_1 = 0.1 \)

\[
\begin{array}{cccccccccccc}
\text{k} & \text{ICF} & 0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\
1 & 3 & 0 & 2 & 2 & 3 & 4 & 5 & 3 & 10 & 9 & 3 & 6 & 7 & 0 & 1 & 0 & 1 & 5 \\
2 & 0 & 0 & 1 & 2 & 2 & 4 & 6 & 8 & 9 & 4 & 0 & 4 & 2 & 4 & 3 & 2 & 4 & 9 \\
3 & 0 & 0 & 0 & 0 & 2 & 1 & 2 & 3 & 24 & 0 & 0 & 1 & 2 & 0 & 3 & 5 & 6 & 15 \\
4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4 & 28 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 5 & 25 \\
\end{array}
\]

Player type 2: \( r_2 = 0.2 \)

\[
\begin{array}{cccccccccccc}
\text{k} & \text{ICF} & 0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\
1 & 16 & 4 & 2 & 4 & 2 & 0 & 0 & 2 & 2 & 12 & 5 & 4 & 2 & 5 & 0 & 0 & 0 & 4 \\
2 & 9 & 2 & 5 & 1 & 5 & 2 & 3 & 1 & 4 & 10 & 2 & 3 & 4 & 3 & 1 & 0 & 2 & 7 \\
3 & 1 & 1 & 3 & 4 & 2 & 4 & 2 & 3 & 12 & 4 & 2 & 0 & 1 & 3 & 5 & 4 & 7 & 6 \\
4 & 0 & 0 & 0 & 1 & 2 & 1 & 1 & 3 & 24 & 1 & 0 & 1 & 0 & 0 & 3 & 2 & 3 & 22 \\
\end{array}
\]

Player type 3: \( r_3 = 0.3 \)

Player type 4: \( r_4 = 0.4 \)

\[
\begin{array}{cccccccccccc}
\text{k} & \text{ICF} & 0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\
1 & 16 & 4 & 2 & 4 & 2 & 0 & 0 & 2 & 2 & 12 & 5 & 4 & 2 & 5 & 0 & 0 & 0 & 4 \\
2 & 9 & 2 & 5 & 1 & 5 & 2 & 3 & 1 & 4 & 10 & 2 & 3 & 4 & 3 & 1 & 0 & 2 & 7 \\
3 & 1 & 1 & 3 & 4 & 2 & 4 & 2 & 3 & 12 & 4 & 2 & 0 & 1 & 3 & 5 & 4 & 7 & 6 \\
4 & 0 & 0 & 0 & 1 & 2 & 1 & 1 & 3 & 24 & 1 & 0 & 1 & 0 & 0 & 3 & 2 & 3 & 22 \\
\end{array}
\]

**Table A3**: Frequency distribution of ICF in Treatment B. For every game and every player type 32 players (=number of ICF=sum of rows).

---

**D. Instructions**

**Welcome**

You are participating in an economic experiment. You will receive your payoff personally and directly after the experiment. The payoff depends on your own decisions and the decisions of your co-players.

Please, turn off your cellphone and similar devices. The entire experiment is conducted on the computer. During the course of the experiment, please do not speak and do not communicate with other participants in any other way.

Below you will find an explanation of the experiment. Please read it carefully. If you have questions notify the experimenter. The experimenter will then answer them. After reading these instructions you will answer several test questions. If you have problems answering these questions, please also notify the experimenter.
Instructions for Treatment S+

- In this experiment you have to make decisions in several periods.
- In each period **groups of 4 players** are built. **You are always player 1** in your group. [In other instructions: Player 2, 3, or 4]
- Each period **each player is endowed with 8 points**.
- Each player can either choose A or B.
- For now choosing B has no impact on your points.
- Choosing A costs
  - you and player 3 4 points each
  - player 2 and 4 8 points each
- If a **threshold of players choosing A** is reached then
  - you and player 3 get 10 points each
  - player 2 and 4 get 20 points each
- The **level** of this threshold is changed **every 8th round**. It is displayed on the screen.
- Each 25 points pays you 1 Euro.

Example

At the beginning of the period you get 8 points. The threshold is 1. Your 3 co-players choose B.

**In case you choose A:**

<table>
<thead>
<tr>
<th></th>
<th>you</th>
<th>player 2</th>
<th>player 3</th>
<th>player 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>points at the beginning</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>of the period</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>costs for choosing A</td>
<td>-4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>profit for reaching the</td>
<td>+10</td>
<td>+20</td>
<td>+10</td>
<td>+20</td>
</tr>
<tr>
<td>threshold</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>period payoff</td>
<td>14</td>
<td>28</td>
<td>18</td>
<td>28</td>
</tr>
</tbody>
</table>

**In case you choose B:**

<table>
<thead>
<tr>
<th></th>
<th>you</th>
<th>player 2</th>
<th>player 3</th>
<th>player 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>points at the beginning</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>of the period</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>costs for choosing A</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>profit for reaching the</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>threshold</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>period payoff</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>