The Role of Rivalry

PUBLIC GOODS VERSUS COMMON-POOL RESOURCES

JOSE APESTEGUIA
Department of Economics and Business
Universitat Pompeu Fabra, Spain
FRANK P. MAIER-RIGAUD
Department of Economics
University of Bonn, Germany
and Max Planck Institute for Research on Collective Goods, Bonn, Germany

Despite a large theoretical and empirical literature on public goods and common-pool resources, a systematic comparison of these two types of social dilemmas is lacking. In fact, there is some confusion about these two types of dilemma situations. As a result, they are often treated alike. In line with the theoretical literature, the authors argue that the degree of rivalry is the fundamental difference between the two games. Furthermore, they experimentally study behavior in a quadratic public good and a quadratic common-pool resource game with identical Pareto-optimum but divergent interior Nash equilibria. The results show that participants clearly perceive the differences in rivalry. Aggregate behavior in both games starts relatively close to Pareto efficiency and converges quickly to the respective Nash equilibrium.

Keywords: *public goods; common-pool resources; social dilemmas; rivalry; experiment*

Despite the seminal papers by Musgrave (1959, 1969) and Samuelson (1954) and a large theoretical and empirical literature on social dilemmas in general, and public goods and common-pool resources in particular, it appears *not* to be generally accepted in the experimental/behavioral literature that both types of games are distinct. A typical example of a public good is national defense, while a typical

AUTHORS' NOTE: This article has benefited from comments during presentations at the University of Bonn, University of Cologne, Indiana University at Bloomington, and Max Planck Institute for Research on Collective Goods. In particular, we thank T. K. Ahn, Martin Beckenkamp, Martin Dufwenberg, Christoph Engel, Roy Gardner, Heike Hennig-Schmidt, Axel Ockenfels, Axel Ostmann, Elinor Ostrom, Reinhard Selten, Burkhard Schipper, James M. Walker, and the Max Planck library team. Financial support from the European Union through the TMR research network ENDEAR (FMRX-CT98-0238) and the Spanish Commission on Science and Technology (SEC2003-08105) is gratefully acknowledged. Replication materials are available at http://jcr.sagepub.com/cgi/content/full/50/5/646/DC1/

JOURNAL OF CONFLICT RESOLUTION, Vol. 50 No. 5, October 2006 646-663
DOI: 10.1177/0022002706290433

example of a common-pool resource is a fishery. Clearly, while it is not possible to restrict the enjoyment of the former, the fish caught by one individual is not available to other users anymore.[1] This distinction has led many authors to propose a categorization of goods on the basis of excludability and rivalry.[2] According to the latter, a public good has two essential attributes: nonexcludability and nonrivalry in consumption. A common-pool resource, however, is nonexcludable but rival. The possibility of nonrival consumption by multiple consumers is the major feature distinguishing public goods from common-pool resources. Nonexcludability—that is, the difficulty of excluding nonpaying consumers from consumption—is a feature that both types of goods share.

Nonexcludability, together with the fact that public goods and common-pool resources can be reduced to a prisoner's dilemma game[3] (Ledyard 1995; Ostrom 1990; Gintis 2000; Camerer 2003; Sandler and Arce 2003), has led many authors to treat both social dilemma games as equivalent. Among these authors are some that claim that both games are strategically equivalent (see, e.g., Ledyard 1995; Gintis 2000, 257; Camerer 2003, 45-6). Based on this belief, the difference between public goods and common-pool resources has often been reduced to frames or different representations of one and the same game. From that perspective commons, resource or common-pool dilemmas are considered to be take-some frames of public good games, whereas the term *public good* is reserved for a give-some frame of the same game[4] (see, e.g., Brewer and Kramer 1986; Fleishman 1988; van Dijk and Wilke 1995; McCusker and Carnevale 1995; Sell and Son 1997; Elliott and Hayward 1998; van Dijk et al. 1999; van Dijk and Wilke 2000). In summary, there is a literature that claims

1. Many empirical applications exist of the two concepts that demonstrate that the distinction is crucial for policy and institutional design (see, e.g., Ostrom 1990; Seabright 1993; Ostrom, Gardner, and Walker 1994; Cornes and Sandler 1996). Gaspart and Seki (2003) provide a good example for the two types of games describing a fishery. Typically, fisheries are common-pool resources, but the local fishery analyzed by them institutionally transforms this common-pool resource into a public good by equally distributing the catch among villagers after each day of fishing.

2. Samuelson (1954) introduced the polar definition of private versus public goods based on their nonrivalry in consumption, and Musgrave (1959, 1969) suggested the criterion of exclusion in addition to rivalry, adding common-pool resources and club goods to the definition. See also Samuelson (1955) and Musgrave (1983), as well as, for example, Taylor (1987), Cornes and Sandler (1996), and Bowles (2003).

3. Consider a game that belongs to the broad class of symmetric games, with a symmetric Nash equilibrium that is Pareto dominated by a different symmetric action profile that is not equilibrium. If one reduces such a game to a 2×2 game where the symmetric Nash equilibrium is Pareto dominated by the alternative symmetric action profile, with the latter not being a Nash equilibrium, then it is obvious that one gets the structure of a prisoner's dilemma game. Clearly, symmetric common-pool resource games and public good games belong to the above-mentioned class of games. Note also that symmetric Cournot games and Bertrand games also belong to this class of games.

4. A give-some frame presents the dilemma situation as one in which individually owned resources have to be contributed to a common undertaking, whereas in a take-some frame, the dilemma consists of leaving resources in the common undertaking. For an experimental analysis of give-some and take-some framing effects in a public good environment, see Andreoni (1995a); Sonnemans, Schram, and Offerman (1998); Willinger and Ziegelmeyer (1999); or Park (2000).

that common-pool resources and public goods are the same, and it consequently uses the label *common-pool resource* for a particular type of framed public good game.[5]

An explicit example of this is provided by Gintis (2000, 257-8), who writes,

> While common pool resource and public goods games are equivalent for *Homo Oeconomicus*, people treat them quite differently in practice. This is because the status quo in the public goods game is the individual keeping all the money in the private account, while the status quo in the common pool resource game is that the resource is not being used at all. This is a good example of a *framing effect*, since people measure movements from the status quo and hence tend to undercontribute in the public goods game and overcontribute (underexploit) in the common pool resource game, compared to the social optimum.

In this article, we first establish theoretically that public good and common-pool resource games, as used in the experimental literature, are two distinct types of social dilemmas. We show that the distinguishing feature of these two types of games lies in the distributional factor that determines whether the good is rival or nonrival. This difference gives rise to two distinct strategic environments. Based on these theoretical differences, we devise an experiment that tests whether the theoretical differences have an impact on behavior in the two games. That is, our aim is to assess whether the theoretical difference between the two types of goods also has behavioral implications. For that purpose, we contrast a quadratic public good game with interior Nash equilibrium (see, e.g., Chan et al. 1996; Sefton and Steinberg 1996; Isaac and Walker 1998; Laury, Walker, and Williams 1999) with a standard common-pool resource game (see, e.g., Ostrom, Gardner, and Walker 1994; Keser and Gardner 1999; Beckenkamp 2002; Casari and Plott 2003). We chose parameters in which the differences between the two types of games are reduced to a minimum. First, to guarantee that the structural differences between the two games cannot be attributed to framing, both games are framed as give-some games. Second, the Pareto solutions in both games are identical in terms of actions and payoffs. Third, the symmetric interior Nash predictions are located at symmetric points from the extremes of the individual action space and involve the same payoffs. The experimental results clearly show that starting from cooperative levels, aggregate behavior in both games tends to the respective Nash equilibrium. This clearly indicates that the differences in rivalry affect behavior, strengthening the importance of differentiating between the two types of goods.

The article is organized as follows. The first subsection of the second section introduces the typical public good and common-pool resource games found in the experimental literature. The second subsection discusses the role of rivalry as the distinguishing feature between public goods and common-pool resource games *in a general setting*. The third section discusses the experimental design. In the fourth

5. Note that different labels may not be problematic as long as authors are aware of the difference and explicitly state that identical labels are used for different games.

section, the experimental findings are presented, and the fifth section concludes with a discussion and summary.

PUBLIC GOODS AND COMMON-POOL RESOURCE GAMES

THE EXPERIMENTAL GAMES

In this section, we introduce two particular games that represent a public good and a common-pool resource game. These games are taken from the experimental literature and are the games that we subsequently analyze experimentally. We also introduce a first theoretical comparison of the two games, showing that the distinguishing feature between both games is the degree of rivalry.

A Public Good Game

In the following, we introduce a quadratic public good game with an interior symmetric Nash equilibrium. We concentrate on such a class of public good games because common-pool resource games are typically characterized by an interior Nash equilibrium. Since we are interested in the role of rivalry as the critical difference between the two types of games, we keep the differences between the two games as minimal as possible.

The following formulation draws from Isaac and Walker (1998).[6] There are n identical players, $N = \{1, . . ., n\}$, each one with an endowment of $e \in \Re_{++}$. Each player i must decide how much to invest in the public good y, $x_i \in [0, e]$. The level of the public good is determined according to the technology

$$y = g(x) = [a\Sigma_{h \in N} x_h - b(\Sigma_{h \in N} x_h)^2](1/n), \tag{1}$$

where $x \in [0, e]^n$. All resources not invested in the public good are allocated to a private account with a constant marginal return c. Hence, individual i's payoff function is given by

$$u_i(x) = [a\Sigma_{h \in N} x_h - b(\Sigma_{h \in N} x_h)^2](1/n) + c(e - x_i). \tag{2}$$

Individual i's best-reply function is

$$x_i^{PG}(x_{-i}) = \max\ \{0, [(a - cn)/2b] - \Sigma_{h \neq i} x_h\}, \tag{3}$$

6. For other formulations of quadratic public good games with interior Nash equilibria, see Sefton and Steinberg (1996) (in their NE treatment), Chan et al. (1996), and Laury, Walker, and Williams (1999). Sefton and Steinberg (1996) (in their DE treatment), Willinger and Ziegelmeyer (1999, 2001), and Falkinger et al. (2000) study public good games with a unique interior dominant strategy equilibrium by making the private account quadratic. Although this manipulation resulted in a quadratic payoff function, the underlying public good remained linear. Quadratic public good games without an interior Nash equilibrium have been analyzed by Issac and Walker (1991) and Isaac, McCue, and Plott (1985).

where $x_{-i} = (x_1, \ldots, x_{i-1}, x_{i+1}, \ldots, x_n)$. Solving (3) under symmetry, one gets the unique symmetric Nash equilibrium

$$x_i^{*PG} = (a - cn)/2bn \qquad \text{for all } i \in N. \tag{4}$$

It is well known that applying the logic of backward induction to the finite repetition of the public good game results in (4) being also the unique symmetric subgame perfect equilibrium of the finitely repeated public good game.

The unique symmetric Pareto solution of the public good game is obtained by optimizing $\Sigma_{h \in N} u_h(x)$ over $\Sigma_{h \in N} x_h$:

$$\mathrm{x}_i^{PG-P} = (a - c)/2bn \qquad \text{for all } i \in N. \tag{5}$$

A Common-Pool Resource Game

The following is a standard formulation of a common-pool resource game that draws from Walker, Gardner, and Ostrom (1990).[7] Denote by $i \in N = \{1, \ldots, n\}$ the ith player in the common-pool resource (CPR) game that is endowed with $e \in \Re_{++}$ and has to decide how much of his or her endowment to allocate to the common-pool resource $x_i \in [0, e]$. Player i's payoff for the resources allocated to the common pool are represented by

$$h(x)(x_i / \Sigma_{h \in \mathrm{N}} x_h) = [a\Sigma_{h \in N} x_h - b(\Sigma_{h \in N} x_h)^2](x_i / \Sigma_{h \in N} x_h). \tag{6}$$

As in the case of the public good game, all resources not invested in the common pool are allocated to a private account with a marginal return of c. Hence, player i's total payoff function is

$$v_i(x) = [a\Sigma_{h \in N} x_h - b(\Sigma_{h \in N} x_h)^2](x_i / \Sigma_{h \in N} x_h) + c(e - x_i). \tag{7}$$

Individual i's best-reply function, the unique symmetric Nash equilibrium, and the unique symmetric Pareto solution in the common-pool resource game are, respectively,

$$x_i^{CP}(x_{-i}) = \max\,\{0, (1/2)[[(a - c)/b] - \Sigma_{h \neq I} x_h]\}, \tag{8}$$

$$x_i^{*CP} = (a - c)/b(n + 1) \qquad \text{for all } i \in N, \tag{9}$$

$$x_i^{CP-P} = (a - c)/2bn \qquad \text{for all } i \in N. \tag{10}$$

7. For other formulations of quadratic common-pool resource games, see Clark (1980); Walker and Gardner (1992); Ostrom, Gardner, and Walker (1994); Herr, Gardner, and Walker (1997); Beckenkamp and Ostmann (1999); Keser and Gardner (1999); Walker et al. (2000); Beckenkamp (2002); Casari and Plott (2003); Margreiter, Sutter, and Dittrich (2005); and Apesteguia (2006). In the psychological literature, common-pool resource (CPR) games are generally implemented as linear threshold CPRs, alternatively known as Nash demand games. See, for example, Suleiman and Rapoport (1988); Budescu, Rapoport, and Suleiman (1995); and Budescu and Au (2002). There also exist experimental CPR studies in nonstrategic, decision-theoretic environments (see, e.g., Hey, Neugebauer, and Sadrieh 2004).

TABLE 1
Experimental Parameters and Theoretical Benchmarks

	Nash Equilibrium		Pareto Solution	
	x_i	*Individual Payoffs*	x_i	*Individual Payoffs*
Public good	20	180	50	225
Common-pool resource	80	180	50	225

NTE: The parameters used in the experimental study are as follows: $n = 4$, $a = 6$, $b = .0125$, $c = 1$, $e = 100$.

Note that the symmetric Pareto solution is the same in both games. Table 1 gives the theoretical predictions for the public good and common-pool resource games for the parameters used in the experimental study.

The values of the parameters were chosen so that (1) all predictions are in integer numbers; (2) payoffs from playing the symmetric Nash equilibria are the same in both games, and since the symmetric Pareto solution is the same for both games, the gain in efficiency associated with a switch from the Nash equilibrium to the Pareto solution is also the same in both games (an increase in payoffs of 20 percent); and (3) the symmetric Nash predictions in the public good and common-pool resource games are located at symmetric points from the extremes of the individual strategy space.

Figure 1 draws the best-reply functions in both games, together with the Pareto reply function, common to both games. It displays the unique symmetric Nash equilibrium in the CPR game, as well as the unique symmetric Nash equilibrium in the public good (PG) game at the intersections of the respective best-reply functions with the symmetry line. In addition, the figure shows the symmetric Pareto efficient allocation for both games at the intersection of the symmetry line with the individual Pareto reply function.

Public Good versus Common-Pool Resource Games

The only difference between the two games is reflected in equations (1) and (6). Equation (1), the individual payoff function from allocations to the public good, reflects the nonrivalry property of public goods. The payoffs derived from the public good on the part of a player do not reduce the payoffs derived from the other players. In other words, for any $x \in [0, e]^n$, all $i \in N$ have the same payoff from the public good.

On the other hand, equation (6), the individual payoff function from allocations to the common pool, captures the rivalry property by introducing an *individual distributional factor* $(x_i / \Sigma_{h \in N} x_h)$.[8] In this case, $x_i / \Sigma_{h \in N} x_h$ represents a proportional distribution. The higher x_i in relation to $\Sigma_{h \in N} x_h$, the higher the appropriation of i

8. The term *distributional factor* is used to distinguish it clearly from institutional arrangements designed to manage a particular resource. From that perspective, terms such as *appropriation rule* or *sharing rule*, often found in the literature, may be misleading terms to describe properties of the good.

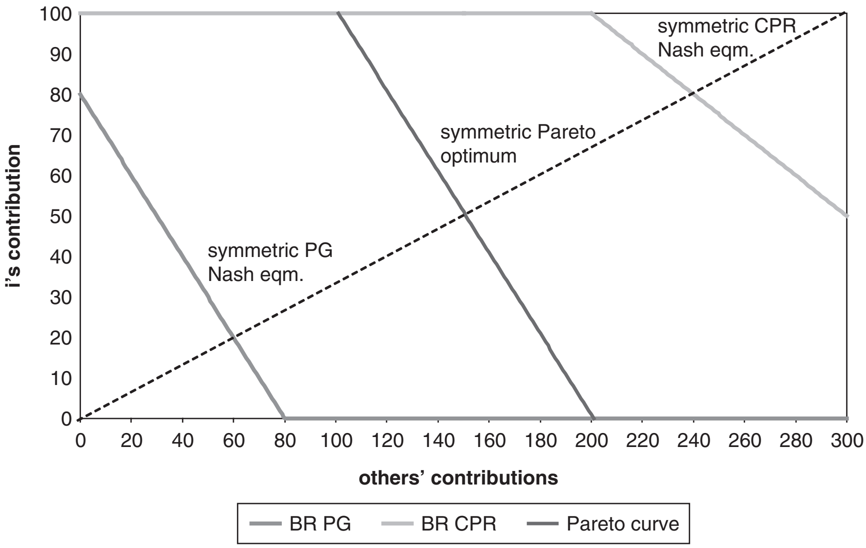

Figure 1: Best-Response (BR) Functions
NOTE: PG = public good; CPR = common-pool resource.

from the common-pool resource. Therefore, in the case of the common pool, the returns from the contributions of all players ($a\Sigma_{h \in N} x_h - b(\Sigma_{h \in N} x_h)^2$) are fully distributed to the individual players on the basis of the individual distributional factor ($x_i/\Sigma_{h \in N} x_h$). That is, the units from the common pool consumed by player i are not available anymore to any other player $j \neq i$.

THE ROLE OF RIVALRY

The Experimental Games section introduced two particular games, a quadratic public good game and a common-pool resource game that we subsequently study experimentally. The preceding section also pointed to the differences between the two types of social dilemmas. In the following, we introduce *general* definitions of public good and common-pool resource games. In these general definitions, we do not impose any restriction on symmetry or on the production functions from the public good, the common pool, and the private accounts. The only assumption we make concerns the individual distributional factor from the common pool. We will assume a *proportional* distributional factor, although we do not restrict it to a *symmetric* distributional factor. Of course, other distributional factors could be (and in fact sometimes are) used.[9] Then, by restricting the classes of possible public good

9. For a detailed discussion of different distributional factors and their consequences for the type of game, see Beckenkamp (forthcoming) and Rapoport and Amaldoss (1999). Gunnthorsdottir and Rapoport (forthcoming) conducted an experimental study of a proportional and an egalitarian distributional factor in an intergroup competition game based on a linear public good.

and common-pool resource games, we show that these two types of games cannot be taken in general to be equal, and hence they are fundamentally different.

We introduce the following notation. The set $N = \{1, . . ., n\}$, $n \geq 2$, is the set of players, indexed by i, and $X_i = [0, e_i]$ is player i's strategy space, $e_i \in \Re_{++}$, $x_i \in X_i$, $X = X_1 \times \cdots \times X_n$, and $x = (x_1, . . ., x_n) \in X$.

Definition 1 (public good game). Denote by $\Gamma_1 = (N, X, U)$ the public good game, where the sets N and X are defined as above, and $U = U_1 \times \cdots \times U_n$, where $U_i : X \rightarrow \Re$ is the payoff function of player i that is decomposed into functions $G : X \rightarrow \Re$ (the public good production function) and $C_i : X_i \rightarrow \Re$ (the private account payoff function), according to $U_i(x) = G(x) + C_i(x_i)$.

Definition 2 (common-pool resource game). Denote by $\Gamma_2 = (N, X, V)$ the common-pool resource game, where the sets N and X are defined as above, and $V = V_1 \times \cdots \times V_n$, where $V_i : X \rightarrow \Re$ is player i's payoff function that is decomposed into functions $H : X \rightarrow \Re$ (the aggregated common-pool production function) and $D_i : X_i \rightarrow \Re$ (the private account payoff function), according to $V_i(x) = H(x)(\alpha_i x_i / \Sigma_{h \in N} \alpha_h x_h) + D_i(x_i)$, $\Sigma_i \alpha_i = 1$, and $\alpha_i \geq 0$ for all $i \in N$.

Proposition 1: There is no configuration of functions G, C_i, H, and D_i, such that $\Gamma_1 \equiv \Gamma_2$.

Proof. To show that, in general, $\Gamma_1 \equiv \Gamma_2$ does not hold, we only need to find a domain where such identity cannot hold. For simplicity, we do this by restricting ourselves to the classes of CPR and PG games were the private accounts are linear, the aggregated common-pool production function is strictly concave in $\Sigma_{h \in N} x_h$, and $\alpha_i = \alpha_j$ for every $i, j \in N$. Now, assume, by way of contradiction, that there exist $G(x)$, $C_i(x_i)$, $H(x)$, and $D_i(x_i)$ such that $U_i(x) \equiv V_i(x)$ for all $i \in N$ and for all $x \in X$. Then, take any $x \in X$ and $i, j \in N$, $i \neq j$ with $x_i \neq x_j$. Hence, $U_i(x) \equiv V_i(x)$ and $U_j(x) \equiv V_j(x)$ for all $x \in X$ imply that

$$G(x) = H(x)(x_i / \Sigma_{h \in N} x_h) + [D_i(x_i) - C_i(x_i)], \quad (11)$$

$$G(x) = H(x)(x_j / \Sigma_{h \in N} x_h) + [D_j(x_j) - C_j(x_j)]. \quad (12)$$

Setting (11) and (12) equal and solving for $H(x)$, one gets

$$H(x)((x_i - x_j)/ \Sigma_{h \in N} x_h) = [D_j(x_j) - D_i(x_i)] - [C_j(x_j) - C_i(x_i)]. \quad (13)$$

Now, since D_h and C_h are assumed to be linear, let $D_h(x_h) = a + bx_h$ and $C_h(x_h) = c + dx_h$, where a, b, c, and d are real value parameters. Hence, (13) implies that

$$H(x) = (d - b)\, \Sigma_{h \in N} x_h,$$

which contradicts our initial assumption on the strict concavity of the aggregated common-pool production function. □

The proof of proposition 1 shows that public good and common-pool resource games cannot be taken in general as identical social dilemma games by restricting the production function of the CPR game to be concave and the private accounts to be linear. Clearly, such classes of public good and the common-pool resource games are considerably broad since they encompass the class of experimental games studied in this article, the standard and intensively studied linear public good games, and the standard CPR experimental games.

EXPERIMENTAL DESIGN

The experiments were conducted at the Experimental Economics Laboratory at the University of Bonn using the z-Tree software developed by Fischbacher (1999). At the beginning of each session, participants were randomly assigned to one of the sixteen computer terminals. Before the session started, participants first had to read the instructions. To check if participants understood the instructions, three test questions were given.[10] The values used in the test questions were publicly drawn by randomly chosen participants from two urns[11] and announced. The experiment was started only after all participants had correctly answered all test questions.

We ran two sessions for each game, for a total of eight independent observations, respectively. In each session, sixteen participants were randomly divided into groups of four to play a give-some frame of either the CPR or the PG game for twenty periods.[12] Participants knew that they would remain in the same group for twenty periods, but they did not know with whom they were playing. At the end of each turn, participants received information on their decision, aggregate decisions of all other players, the payoffs from account 1 (the common-pool or public good account) and account 2 (the private account), the sum of the payoffs from both accounts in that period, and their total payoff so far. The parameterization of the PG game, based on the payoff function (2), was

$$u_i(x) = [6\Sigma_{h \in N} x_h - (1/80)(\Sigma_{h \in N} x_h)^2](1/4) + (100 - x_i). \quad (14)$$

The parameterization of the CPR game, based on the payoff function (7), was

$$v_i(x) = [6\Sigma_{h \in N} x_h - (1/80)(\Sigma_{h \in N} x_h)^2](x_i / \Sigma_{h \in N} x_h) + (100 - x_i). \quad (15)$$

Communication was not allowed throughout the experiment.

10. Both the instructions and the test questions are available at http://jcr.sagepub.com/cgi/content/full/50/5/646/DC1/

11. One urn contained all entries of the *Y* column of the total payoff table, and the other contained all values of the *X* row. Even though participants were equipped with calculators, the numbers were chosen such that the test questions could be answered based on the entries in the tables provided.

12. The nonrandom matching protocol, where group membership remains fixed across periods, was chosen, although potential repeated game effects may interact with the inherent strategic differences of the two games, in order to have a sufficient number of independent observations. See the Sequential Dependencies section for an analysis of sequential dependencies.

TABLE 2
Summary Statistics

	PG	*CPR*
Average allocation (periods 1 to 20)	21.4	74.8
Average allocation (periods 1 to 10)	23.3	72.2
Average allocation (periods 11 to 20)	19.5	77.4
Average payoffs	179.4	189.3
Standard deviation of average allocations	4.0	3.6
Average of standard deviation of individual behavior	21.7	20.4

NOTE: PG = public good; CPR = common-pool resource.

RESULTS

We begin by addressing the main question investigated in this article—namely, whether the investment level in PG games significantly differs from the investment level in CPR games. Table 2 reports summary statistics on average investments for the entire experiment, as well as for the first and the second halves. Also, the average payoffs, the standard deviations of the average allocations in the eight groups, and the average of the standard deviations at the individual level are reported in the table.

Result 1: Aggregate investment in the PG game is statistically different from investment in the CPR game.

Support to result 1. The permutation test on the basis of the average allocations per group yields a significance of 0.01 percent (two-sided).[13] Furthermore, consider Figure 2, where the time series of average allocations per treatment are shown, and Figure 3, where the histogram of all individual decisions by treatment is reported.

Clearly, investment decisions in both games sharply differ. This indicates that players are sensitive to the different incentive structures determined by the distributional factor.

Having shown that *investment decisions* differ between games, it remains to be shown whether the *pattern of behavior* exhibited by players also differs between games. The distinction between investment levels (investment decisions) and the pattern of behavior is important. Even though investment levels clearly differ, behavioral strategies may still be the same.

Result 2: The pattern of behavior in both games is qualitatively similar.

Support to result 2. Figure 2 shows that aggregate allocations in both PG and CPR games start at levels in between the symmetric Pareto solution and the respective

13. See Siegel and Castellan (1988) for a reference on the statistical tests used in this article.

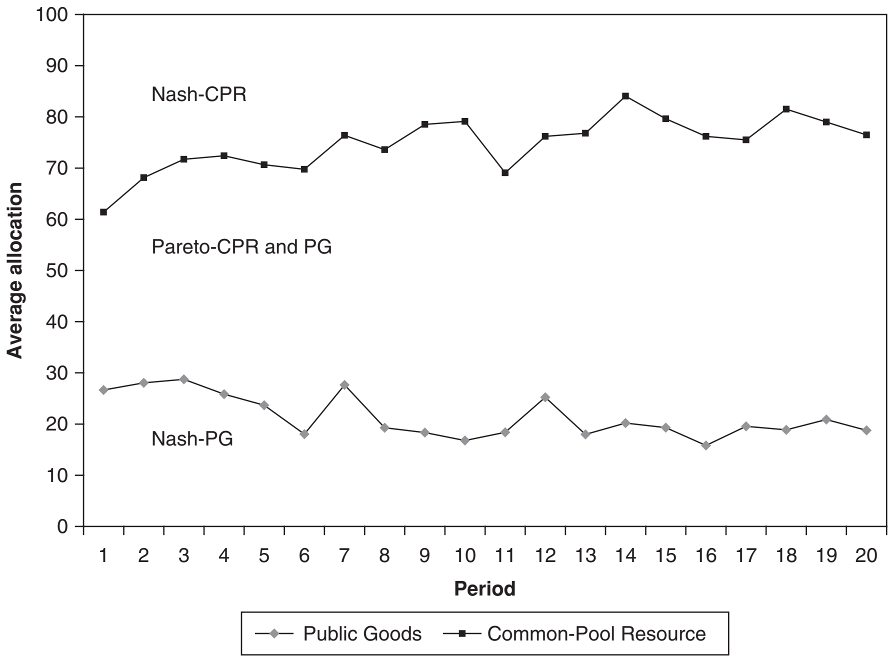

Figure 2: Time Series of Average Allocations Per Treatment
NOTE: PG = public good; CPR = common-pool resource.

Nash equilibria, and they tend to converge to the respective Nash equilibria. In fact, with respect to the tendency, average investment per group in the first half of the PG experiments is higher than that in the second half, while in the CPR experiments, the relation is the opposite. The Wilcoxon signed-ranks test yields significance at the .0386 level for the PG case and at the .0039 level for the CPR case (both one-sided). Furthermore, in both games, the null hypotheses of no difference between average allocations in the second half of the experiment at the group level, with respect to the respective Nash equilibrium, cannot be rejected at a 5 percent significance level.

It is illuminating that average payoffs in the CPR experiment do not significantly differ from those in the PG game. The permutation test does not reject at a 5 percent significance level the null hypothesis of equal average payoffs between the PG and CPR experiments.

However, this does not imply that behavior in CPR experiments is the mirror image of behavior in PG experiments. In fact, when contrasting the distribution of individual decisions between the PG experiments and the truncated distribution of the CPR experiments (i.e., we take values y_i, where $y_i = 100 - x_i$), the Kolmogorov-Smirnov two-sample test yields a significance at the .01 level.

We conclude that participants in the experiments were sensitive to the unique difference between the two games: the degree of rivalry, as captured by the

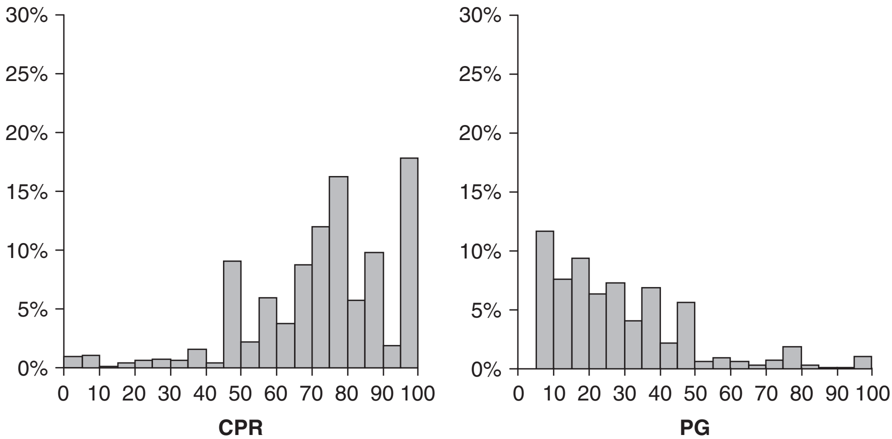

Figure 3: Histograms of Individual Investments in the Public Good (PG) and Common-Pool Resource (CPR) Experiments

distributional factor. Hence, it appears not only that both types of games are theoretically and conceptually different, but these differences are also reflected in different investment levels. Nevertheless, the pattern of behavior seems to be qualitatively similar when the Pareto solution and the Nash equilibrium are taken as reference points.

A LOOK AT INDIVIDUAL DIFFERENCES

So far, the analysis has been based on group-level data. In this subsection, we turn to individual behavior. It has consistently been shown that behavior at the individual level is very heterogeneous in dilemma experiments. To check for this regularity found in the literature, we compute for the respective game (equations (3) and (8)) the average of the squared differences between the observed data and the individual best-reply functions over all periods at the individual level. Figure 4 reports the distribution of the individual average squared differences.

The range in Figure 4 goes from 0 to a maximum of 2,500,[14] with twenty-five intervals of length 100. Note that the distributions in Figure 4 are quite dispersed. The mean deviation in the CPR (PG) experiments is 635.3 (839.5), with a standard deviation of 455.4 (462.1).

Classifying individuals as best repliers if they deviate 15 percent or less from the best reply in action space, about 20 percent of participants in the CPR experiments

14. Note that if we take the individual decision and the best-reply prediction as uniform random variables, the difference in expectation of the order statistics is 100/3, implying a squared difference of about 1,110.

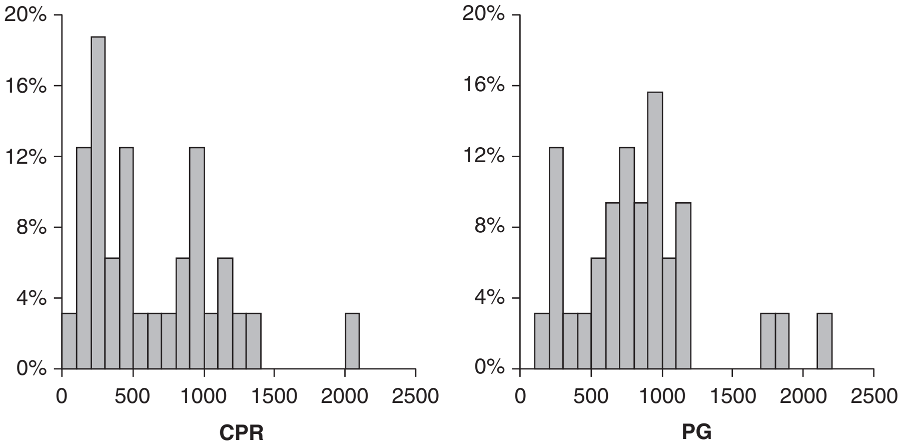

Figure 4: Histograms of Individual Average Squared Differences between Observed Data and Best-Reply Predictions in the Public Good (PG) and Common-Pool Resource (CPR) Experiments

and about 10 percent of participants in the PG experiments fall in that category. However, if we were to take players as exhibiting behavior substantially deviating from the best reply when they deviate by 30 percent or more in action space[15] from the best-reply prediction, about 18 percent of the players in the CPR experiments and about 25 percent in the PG experiments are characterized that way. Consequently, it appears that, consistent with previous findings, individual behavior in our experiments is quite diverse.

SEQUENTIAL DEPENDENCIES

Our experimental games were conducted in partner design—that is, the same group of individuals interacted throughout the entire experiment. By doing so, we adhered to the early experimental practice in both PG and CPR experiments, allowing us to gain a relatively high number of independent observations for the statistical analysis. A natural alternative to our design choice is to use random matching. Random matching has very important advantages since it minimizes reputation effects and other sequential dependencies. As a result, it is interesting to analyze to what extent sequential dependencies were present in our data. Of course, the ultimate test for such a question encompasses the comparison of experiments with and without random matching. Such a comparison is out of the scope of the present study, but we can, nevertheless, make some tests in this respect.[16]

15. See the previous footnote.
16. Botelho et al. (2005) study these sorts of questions in the context of public good games.

Individuals received feedback on the behavior of the opponents, in the form of aggregate contributions in the group, throughout the experiment. In Figure 1, we showed that according to best reply, a negative relation between others' allocations and one's allocation should hold. On the other hand, a positive relation could indicate some kind of sequential dependency (e.g., a taste for conformity with the behavior of others).

We measure such (first-order) dependencies by computing the Spearman rank-order correlation coefficient for each individual between the individual allocation decisions and the last observed sum of allocations of the opponents. Of the thirty-two individual coefficients in the PG (CPR) experiments, twelve (nineteen) were negative. A binomial test yields no difference at standard significance levels between the number of positive and negative coefficients in both experiments. That there is not a predominantly negative relation is not surprising given the remarkable deviations from best reply that we could observe at the individual level in Figure 3. Furthermore, the no-significance result suggests that (first-order) sequential dependencies between individuals seem not to be significantly present in our data.

RELATED LITERATURE

Our experimental findings in the quadratic PG and the quadratic CPR game are generally in line with previous experimental evidence.

The literature on quadratic public good games reports similar investment patterns to those observed here: behavior starts around the Pareto solution and then declines toward the Nash equilibrium with repetition. Interestingly, both (1) experimental studies of quadratic public good games, where the interior Nash equilibrium is in dominant strategies (see Falkinger et al. 2000; Willinger and Ziegelmeyer 1999), and (2) those without an interior Nash equilibrium in dominant strategies (see Isaac and Walker 1998 and Laury, Walker and Williams 1999)[17] show the mentioned pattern from Pareto to Nash but at lower rates that those found here. That is, the convergence to Nash that we observe is quicker than the convergence reported in the literature. The determinants of such a difference are difficult to identify since there are many design differences between our experiments and those mentioned above.[18] However, this is an interesting observation that should be investigated in future research.[19]

17. See Anderson, Goeree, and Holt (1998) for a theoretical discussion of these results. Laury and Holt (forthcoming) provide an overview of the public good (PG) literature with interior Nash equilibrium. For recent experimental studies of linear public good games, see, for example, Maier-Rigaud, Martinsson and Staffiero (2005), Brandts and Schram (2001), Keser and van Winden (2000), Gächter and Fehr (1999), Palfrey and Prisbrey (1997), Andreoni (1995b), and Laury, Walker, and Williams (1995).

18. Charness, Frechette, and Kagel (2004) have shown that payoff tables reduce cooperativeness in the context of gift exchange experiments. Gürerk and Selten (2006) find the opposite effect in the context of oligopoly experiments. In Laury, Walker, and Williams (1999), conversion was quicker in the treatments, with more detailed information containing payoff tables than in the treatments without. In our experiment, conversion is even quicker than in their detailed information treatment.

19. For an experimental study on the rates of convergence to equilibrium in 3 × 3 games, see Ehrblatt et al. (2005).

For the CPR game, there is conflicting evidence on the tendency of aggregate decisions through time. This seems to depend on a variety of issues, such as the endowment, the group size, and so on. Nevertheless, the general pattern of an increase of investment toward the Nash equilibrium has also been observed in the low-endowment treatment in Walker, Gardner, and Ostrom (1990); Ostrom and Walker (1991); Ostrom, Gardner, and Walker (1994); and Apesteguia (2006). On the other hand, for the high-endowment treatment, others (Keser and Gardner 1999; Gardner, Moore, and Walker 1997; Walker, Gardner, and Ostrom 1990; see also Casari and Plott 2003) have found investments above the Nash equilibrium.

Inspired by the theoretical results of Rapoport and Amaldoss (1999), Gunnthorsdottir and Rapoport (forthcoming) study the two distributional factors analyzed here in the context of an intergroup competition game. The game within the group was a linear public good game with a corner solution that determined the probability of winning a fixed award that, afterwards, was split according to a *proportional* or an *egalitarian* distributional factor. The proportional distributional factor corresponds here to the CPR experiment, while the egalitarian distributional factor corresponds to the PG experiment. Although there are many differences in the design of their experiment and ours, their findings for the proportional distributional factor are similar to the pattern observed in the present CPR game. The main difference concerns the egalitarian distributional factor, where Gunnthorsdottir and Rapoport found significantly higher contributions that only slowly converged to the Nash equilibrium in their experiment.

CONCLUSION

The aim of this study was to shed some light on the commonalities and differences between common-pool resources and public goods. We designed a PG and a CPR game with an identical quadratic production function to compare both games on a theoretical and experimental level.

We show that, in contradiction to the common belief that CPR and PG games are theoretically identical, the two games are in fact distinct games. We show that this difference is based on rivalry as captured by a proportional distributional factor.

The experimental results clearly support the theoretical result that both games are different. Investment decisions in the public good experiments are statistically different from those in the common-pool resource ones. Given that both games were framed as give-some games, this difference cannot be attributed to framing. Hence, the results clearly indicate that participants were sensitive to the rivalry structure of the strategic situation. Despite this difference reflecting the structure of the two games, there appear to be some behavioral similarities. In the CPR game, the aggregate Nash equilibrium investment level is above the Pareto efficient one, whereas in the PG game, the aggregate Nash equilibrium is below the Pareto efficient level. In both games, aggregate investment approaches the Nash equilibrium over time. At the beginning, the Pareto optimum and, later, the Nash equilibrium appear to be behaviorally relevant. Aggregate behavior in both games is surprisingly similar in the sense that it starts in the neighborhood of the Pareto optimum and moves rather quickly to the respective aggregate Nash equilibrium.

REFERENCES

Anderson, S. P., J. K. Goeree, and C. A. Holt. 1998. A theoretical analysis of altruism and decision error in public goods games. *Journal of Public Economics* 70:297-323.

Andreoni, J. 1995a. Warm-glow versus cold-prickle: The effects of positive and negative framing on cooperation in experiments. *Quarterly Journal of Economics* 110:1-21.

———. 1995b. Cooperation in public-goods experiments: Kindness or confusion? *American Economic Review* 85:891-904.

Apesteguia, J. 2006. Does information matter in the commons? Experimental evidence. *Journal of Economic Behavior and Organization* 60:55-69.

Beckenkamp, M. 2002. *Sanktionen im Gemeingutdilemma*. Weinheim, Basel: Beltz Verlag.

———. Forthcoming. A game theoretic taxonomy of social dilemmas. *Central European Journal of Operations Research*.

Beckenkamp, M., and A. Ostmann. 1999. Missing the target? Sanctioning as an ambiguous structural solution. In *Resolving social dilemmas*, edited by M. Smithson, 165-80. Philadelphia: Taylor & Francis.

Botelho, A., G. Harrison, L. M. Costa Pino, and E. E. Rutström. 2005. Testing static game theory with dynamic experiments: A case study of public goods. Working paper, University of Central Florida.

Bowles, S. 2003. *Microeconomics: Behavior, institutions, and evolution*. Princeton, NJ: Princeton University Press.

Brandts, J., and A. Schram. 2001. Cooperation and noise in public goods experiments: Applying the contribution function approach. *Journal of Public Economics* 79:399-427.

Brewer, M. B., and R. M. Kramer. 1986. Choice behavior in social dilemmas: Effects of social identity, group size, and decision framing. *Journal of Personality and Social Psychology* 50:543-49.

Budescu, D. V., and W. T. Au. 2002. A model of sequential effects in common pool resource dilemmas. *Journal of Behavioral Decision Making* 15:37-63.

Budescu, D. V., A. Rapoport, and R. Suleiman. 1995. Common pool resource dilemmas under uncertainty: Qualitative tests of equilibrium solutions. *Games and Economic Behavior* 10:171–201.

Camerer, C. 2003. *Behavioral game theory.* Princeton, NJ: Princeton University Press.

Casari, M., and C. R. Plott. 2003. Decentralized management of common property resources: Experiments with a centuries old institution. *Journal of Economic Behavior and Organization* 1486: 1-31.

Chan, K., S. Mestelman, R. Moir, and A. Muller. 1996. The voluntary provision of public goods under varying income distributions. *Canadian Journal of Economics* 29:54-69.

Charness, G., G. R. Frechette, and J. H. Kagel. 2004. How robust is laboratory gift exchange? *Experimental Economics* 7:189-205.

Clark, C. W. 1980. Restricted access to common-property fishery resources: A game theoretic analysis. In *Dynamic optimization and mathematical economics,* edited by P.-T. Liu, 117-32. New York: Plenum.

Cornes, R., and T. Sandler. 1996. *The theory of externalities, public goods and club goods*. Cambridge, UK: Cambridge University Press.

Ehrblatt, W., K. Hyndman, E. Özbay, and A. Schotter. 2005. Convergence: An experimental study. Working paper, New York University.

Elliott, C. S., and D. M. Hayward. 1998. The expanding definition of framing and its particular impact on economic experimentation. *Journal of Socio-Economics* 27:229-43.

Falkinger, J., E. Fehr, S. Gächter, and R. Winter-Ebmer. 2000. A simple mechanism fort the efficient provision of public goods: Experimental evidence. *American Economic Review* 90:247-64.

Fischbacher, U. 1999. z-Tree, Zürich toolbox for readymade economic experiments. Working paper, University of Zürich.
Fleishman, J. A. 1988. The effects of decision framing and other's behavior on cooperation in a social dilemma. *Journal of Conflict Resolution* 32:162-80.
Gächter, S., and E. Fehr. 1999. Collective action as social exchange. *Journal of Economic Behavior and Organization* 39:341-69.
Gardner, R., M. R. Moore, and J. M. Walker. 1997. Governing a groundwater commons: A strategic and laboratory analysis of Western water law. *Economic Inquiry* 35:218-34.
Gaspart, F., and E. Seki. 2003. Cooperation status seeking and competitive behavior: Theory and evidence. *Journal of Economic Behavior and Organization* 51:51-77.
Gintis, H. 2000. *Game theory evolving: A problem-centered introduction to modeling strategic interaction*. Princeton, NJ: Princeton University Press.
Gunnthorsdottir, A., and A. Rapoport. Forthcoming. Embedding social dilemmas in intergroup competition reduces free-riding. *Organizational Behavior and Human Decision Processes*.
Gürerk, Ö., and R. Selten. 2006. The effect of payoff tables on experimental oligopoly behavior. Working paper, University of Erfurt.
Herr, A., R. Gardner, and J. M. Walker. 1997. An experimental study of time-independent and time-dependent externalities in the commons. *Games and Economic Behavior* 19:77–96.
Hey, J., T. Neugebauer, and A. Sadrieh. 2004. An experimental analysis of optimal renewable resource management: The fishery. Working paper, University of York.
Isaac, R. M., K. McCue, and C. Plott. 1985. Public goods provision in an experimental environment. *Journal of Public Economics* 26:1-74.
Isaac, R. M., and J. M. Walker. 1991. On the suboptimality of voluntary public goods provision: Further experimental evidence. *Research in Experimental Economics* 4:211-21.
———. 1998. Nash as an organizing principle in the voluntary provision of public goods: Experimental evidence. *Experimental Economics* 1:191-206.
Keser, C., and R. Gardner. 1999. Strategic behavior of experienced subjects in a common pool resource game. *International Journal of Game Theory* 28:241-52.
Keser, C., and F. van Winden. 2000. Conditional cooperation and voluntary contributions to public goods. *Scandinavian Journal of Economics* 102:23-39.
Laury, S. K., and C. H. Holt. Forthcoming. Voluntary provision of public goods: Experimental results with interior Nash equilibria. In *Handbook of experimental economics results*, edited by C. Plott and V. Smith, vol. 1. New York: Elsevier.
Laury, S. K., J. M. Walker, and A. W. Williams. 1995. Anonymity and the voluntary provision of public goods. *Journal of Economic Behavior and Organization* 27:365-80.
———. 1999. The voluntary provision of a pure public good with diminishing marginal returns. *Public Choice* 99:139-60.
Ledyard, J. O. 1995. Public goods: A survey of experimental research. In *Handbook of experimental economics*, edited by J. H. Kagel and A. E. Roth, 111-94. Princeton, NJ: Princeton University Press.
Maier-Rigaud, F., P. Martinsson, and G. Staffiero. 2005. Ostracism and the provision of a public good: Experimental evidence. Working paper, Max Planck Institute for Research on Collective Goods.
Margreiter, M., M. Sutter, and D. Dittrich. 2005. Individual and collective choice and voting in common pool resource problems with heterogeneous actors. *Environmental and Resource Economics* 32: 241-71.
McCusker, C., and P. J. Carnevale. 1995. Framing in resource dilemmas: Loss aversion and the moderating effects of sanctions. *Organizational Behavior and Human Decision Processes* 61:190-201.
Musgrave, R. A. 1959. *The theory of public finance*. New York: McGraw-Hill.
———. 1969. Provision for social goods. In *Public economics*, edited by J. Margolis and H. Guitton, 124-44. London: McMillan.
———. 1983. Public goods. In *Paul Samuelson and modern economic theory*, edited by E. C. Brown and R. M. Solow, 141-56. New York: McGraw-Hill.
Ostrom, E. 1990. *Governing the commons: The evolution of institutions for collective action*. Cambridge, UK: Cambridge University Press.

Ostrom, E., R. Gardner, and J. M. Walker. 1994. *Rules, games, and common-pool resources*. Ann Arbor: University of Michigan Press.

Ostrom, E., and J. M. Walker. 1991. Communication in a commons: Cooperation without external enforcement. In *Laboratory research in political economy*, edited by T. S. Palfrey, 287-322. Ann Arbor: University of Michigan Press.

Palfrey, T. R., and J. E. Prisbrey. 1997. Anomalous behavior in public goods experiments: How much and why? *American Economic Review* 87:829-46.

Park, E.-S. 2000. Warm-glow versus cold-prickle: A further experimental study of framing effects on free-riding. *Journal of Economic Behavior and Organization* 43:405-21.

Rapoport, A., and W. Amaldoss. 1999. Social dilemmas embedded in between-group competitions: Effects of contest and distribution rules. In *Resolving social dilemmas: Dynamic, structural, and intergroup aspects*, edited by M. Foddy, M. Smithson, S. Schneider, and M. Hogg, 67-85. New York: Psychology Press.

Samuelson, P. 1954. The pure theory of public expenditure. *Review of Economics and Statistics* 36: 387-9.

———. 1955. Diagrammatic exposition of a theory of public expenditure. *Review of Economics and Statistics* 37:350-6.

Sandler, T., and D. G. Arce. 2003. Pure public goods versus commons: Benefit cost duality. *Land Economics* 79:355-68.

Seabright, P. 1993. Managing local commons: Theoretical issues in incentive design. *Journal of Economic Perspectives* 7:113-34.

Sefton, M., and R. Steinberg. 1996. Reward structure in public good experiments. *Journal of Public Economics* 61:263-87.

Sell, J., and Y. Son. 1997. Comparing public goods with common pool resources: Three experiments. *Social Psychology Quarterly* 60:118-37.

Siegel, S., and J. Castellan. 1988. *Nonparametric statistics for the behavioral sciences.* New York: McGraw-Hill.

Sonnemans, J., A. Schram, and T. Offerman. 1998. Public good provision and public bad prevention: The effect of framing. *Journal of Economic Behavior and Organization* 34:143-61.

Suleiman, R., and A. Rapoport. 1988. Environmental and social uncertainty in single-trial resource dilemmas. *Acta Psychologica* 68:99-112.

Taylor, M. 1987. *The possibility of cooperation*. Cambridge, UK: Cambridge University Press.

van Dijk, E., and H. Wilke. 1995. Coordination rules in asymmetric social dilemmas: A comparison between public good dilemmas and resource dilemmas. *Journal of Experimental Social Psychology* 31:1-27.

———. 2000. Decision induced focusing in social dilemmas: Give-some, keep-some, take-some, and leave-some dilemmas. *Journal of Personality and Social Psychology* 78:92-104.

van Dijk, E., H. Wilke, M. Wilke, and L. Metman. 1999. What information do we use in social dilemmas? Environmental uncertainty and the employment of coordination rules. *Journal of Experimental Social Psychology* 35:109-35.

Willinger, M., and A. Ziegelmeyer. 1999. Framing and cooperation in public good games: An experiment with an interior solution. *Economics Letters* 65:323-8.

———. 2001. Strength of the social dilemma in a public goods experiment: An exploration of the error hypothesis. *Experimental Economics* 4:131-44.

Walker, J. M., and R. Gardner. 1992. Probabilistic destruction of common-pool resources: Experimental evidence. *Economic Journal* 102:1149–61.

Walker, J. M., R. Gardner, A. Herr, and E. Ostrom. 2000. Collective choice in the commons: Experimental results on proposed allocation rules and votes. *Economic Journal* 110:212–34.

Walker, J. M., R. Gardner, and E. Ostrom. 1990. Rent dissipation in a limited-access common-pool resource: Experimental evidence. *Journal of Environmental Economics and Management* 19:203-11.