cooperative and Nash equilibrium outcomes increases across the two- and three-person games shown in figures 6.1 and 6.2. Holding the MPCR constant, the gains from cooperation increase with the number of players, since more participants are able to make contributions that are collectively enjoyed by all.

Illustration of the problem quickly becomes intractable with the addition of more players, but this three-person prisoner's dilemma can readily be generalized to any arbitrary number of players N: If everyone contributes to the group exchange, each player earns .7(60)N. The dilemma arises because each player has an incentive to contribute to the private good and earn .7(60)(N – 1) + 60. In the unique Nash equilibrium for the game, each player contributes only to the private good and earns 60 cents.

It is useful to present the public-goods problem in the context of more nearly continuous contributions options. This can be seen from the following general characterization of the voluntary-contributions mechanism. Denote endowments and decisions for each participant with a subscript i: $i = 1 \ldots N$. Each participant has an initial endowment, E_i, of which some amount x_i is contributed to the group exchange, and the remainder $E_i - x_i$ is invested in a private exchange and converted to cash. The individual return from contributions to the group exchange is a function of the sum of contributions by all participants, $V(\Sigma x_j)$. Thus, the problem for each participant is to choose x_i to maximize return on investment R_i, where

$$R_i = E_i - x_i + V(\Sigma_j x_j). \tag{6.2}$$

A public-goods problem arises when contributions to the private exchange are individually optimal, but not optimal for the group. The individual optimality condition requires evaluating the marginal effects of contributions to the public and private exchanges. These conditions can be compared by taking the derivative of (6.2) with respect to individual contributions x_i. This derivative is $-1 + V'(\Sigma x_j)$. In this context, the MPCR is V', and the marginal return of a contribution to the private exchange is 1. Contributions to the private exchange are individually optimal if the MPCR is less than 1, or if $V'(\Sigma x_j) < 1$. Total group income is the sum of all individual returns from the group exchange. If individuals are identical, this may be expressed as the product $N \cdot V(\Sigma x_j)$. Contributions to the group exchange increase aggregate income more than contributions to the private exchange as long as $N \cdot V'(\Sigma x_j) > 1$. Combined, these conditions characterize the free-rider problem:

$$\frac{1}{N} < V'(\Sigma x_j) < 1. \tag{6.3}$$

Notice that a free-rider problem can arise even with a very small group. For example, if the MPCR is between 1/2 and 1, free-riding is predicted for a group of two.

Although neither the number of participants nor the continuity of choices affects the unique, pure-strategy equilibrium in a single-stage implementation of the voluntary contributions mechanism, it is important to observe that other components of the implementation can affect equilibrium predictions. As was the case for collusion in the repeated oligopolies discussed in chapter 4, cooperation can be supported in an infinitely (or indefinitely) repeated game through the use of threats. That is, contributions to the public good can be an equilibrium, if they are supported by a threat to "punish" cheaters with zero contributions to the public good. To avoid the possibility of these "cooperative" equilibria, standard implementations of the voluntary-contributions mechanism typically include an announcement regarding the number periods.

6.3 The Voluntary-Contributions Mechanism: Results

Initial laboratory examinations of the free-rider problem generated widely divergent results. On the one hand, Marwell and Ames (1979, 1980, 1981) and Schneider and Pommerhene (1981) found far less free-riding than predicted by economists. In a wide variety of treatment conditions, participants rather persistently contributed 40 to 60 percent of their token endowments to the group exchange, far in excess of the 0 percent contributions rate consistent with a Nash equilibrium. The only treatment unquestionably to induce free-riding by Marwell and Ames (1981) was the use of a cohort of thirty-two first-year graduate students in economics (who contributed only 20 percent of their endowments to the group project), leading the authors to entitle their paper "Economists Free-Ride, Does Anyone Else?"[4] On the other hand, nearly complete free-riding has been generated in other laboratory contexts (e.g., Kim and Walker, 1984, and Isaac, McCue, and Plott, 1985), particularly in the terminal periods of multiperiod sessions.

Figure 6.3 provides a sense of the variety of outcomes observed in initial investigations. The figure summarizes mean contribution rates for eight sessions reported by Isaac, Walker, and Thomas (1984). Period numbers are listed along the horizontal axis, while mean contribution rates are printed on the vertical axis. Each line represents mean contribution rates for a single ten-period session.

Isaac, Walker, and Thomas were interested in identifying reasons for the differences in contribution rates reported in initial experiments. Consequently, their experiment included a variety of the design features that were varied across earlier

[4] Subsequent investigations have not corroborated this finding of a subject-pool effect. In a different public-goods context, Isaac, McCue, and Plott (1985), for example, report near-zero contributions to a group exchange by a cohort of sociology undergraduates, as well as by several cohorts of economics undergraduates. Similarly, a cohort of presumably "cooperative" human ecologists and anthropologists also engaged in substantial free-riding in the laboratory (Mestelman and Feeny, 1988).

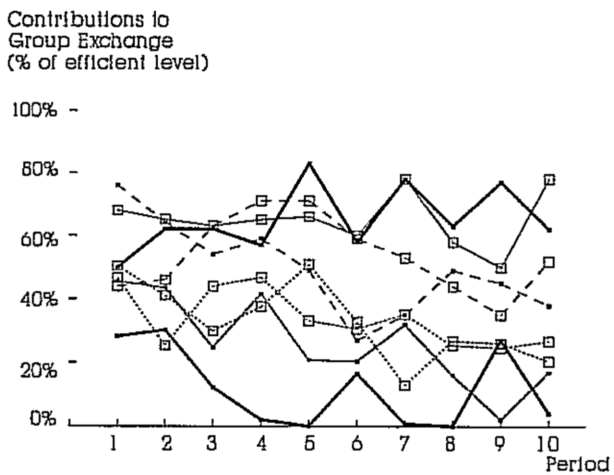

Figure 6.3 Results for Eight Voluntary Contributions Mechanism Sessions, under Various Treatment Conditions (Source: Isaac, Walker, and Thomas, 1984)

experiments, including the size of the group (four and ten), experience levels (inexperienced and experienced) and the MPCR (.30 and .75). Nevertheless, all sessions shared the characteristic that complete free-riding, or a contribution rate of 0, is the unique Nash equilibrium, and that joint income is maximized when all participants contribute all tokens to the group exchange. The primary conclusion that may be drawn from figure 6.3 is that, despite this common prediction, virtually every kind of behavior was observed. Contribution rates ranged from nearly 0 percent (illustrated by the bold line near the horizontal axis of the chart) to roughly 75 percent (as illustrated by the bold line near the top of figure).

Given the diversity of results, some identification of consistent sources of variation is warranted, both as a means of identifying when standard theory works well and as a means of suggesting modifications to the theory when it fails. In the remainder of this section, we consider a variety of potentially important determinants of free-riding, including experience, repetition, and the MPCR.

Repetition

The most obvious difference across the early studies was the number of periods. The 40 to 60 percent contributions rates reported by Schneider and Pommerhene (1981) and Marwell and Ames (1979, 1980, 1981) were for single-period games. Similar contribution rates were observed in initial decision-periods by Isaac, McCue, and Plott (1985) and Kim and Walker (1984). However,

contribution rates decayed substantially when the decision sequence was repeated. For example, in five sessions reported by Isaac, McCue, and Plott (1985), average contribution rates decayed from 38 percent of the efficient contributions level in the initial period to 9 percent in the terminal period.[5]

It is an oversimplification to conclude that contribution rates uniformly diminish with repetition: Some of the series in figure 6.3 decay rather regularly, while others do not. Although an aggregation of contribution rates in figure 6.3 would generate a negative slope, such an aggregation misstates the prominent effect of repetition in certain environments.

For those environments where contribution rates generally diminish with repetition, it is useful to consider reasons for the decay. First, there is a learning effect. Many participants may learn that contributing to the private exchange dominates contributing to the group exchange only after observing several instances of free-riding by other participants. Second, the decay may be a consequence of strategic play. Although participants know that not contributing is a dominant strategy, they may nevertheless contribute in early periods and reserve a noncontribution option as a punishment for the failure of others to contribute.[6]

Andreoni (1988) reports an experiment designed to evaluate these learning and strategic-play explanations. The design turns on the observation that strategic punish/reward play is only potentially useful if participants remain paired in the same group for consecutive periods. A pure-learning effect could be isolated by shuffling the composition of participant groups after each trial. Consequently, Andreoni conducted the following two-treatment experiment. A first "partners" treatment consisted of three sessions with the standard voluntary-contributions mechanism. A second "strangers" treatment was identical, except that instead of leaving the same group intact for ten consecutive periods, participants in a cohort of twenty were randomly and anonymously regrouped after each decision period. Design features common to both treatments included an MPCR of .5, decision groups consisting of five inexperienced participants, and complete information about group size, session length, and the results of each decision period.

Results of this experiment are summarized by the mean contributions rates for the "partners" and "strangers" treatments, shown in figure 6.4. Obviously, contribution rates declined with repetition in each treatment. Contrary to

[5] Mean contribution rates understate efficiency, or the proportion of possible gains from contributing to the group exchange in the Isaac, McCue, and Plott design since these authors induced a diminishing marginal value schedule for contributions to the group exchange. Efficiency extraction rates decayed from 53 percent to 16 percent for the five sessions mentioned in the text. Also, these authors conducted a total seven sessions in their experiment but report summary results on the basis of five sessions. Two sessions were excluded on the basis of aberrant, "irrational" participant decisions.

[6] In a game with a commonly known and finite number of periods, this is not a subgame-perfect Nash equilibrium strategy. However, it is part of *a* Nash equilibrium strategy, and it may have some behavioral appeal.

expectation, however, significantly higher contribution rates were generated in the "strangers" treatment.[7] Andreoni concludes that the contributions pattern is not attributable to strategic motivations (this hypothesis would be supported by significantly higher contributions in the partners treatment). The similar rate of decay in each treatment supports a learning explanation. The difference in contributions rates is provocative. To the extent that strangers do in fact tend to persistently contribute more than partners, a richer set of behavioral motivations (such as altruism, revenge, social norms, and regret theory) merits consideration.

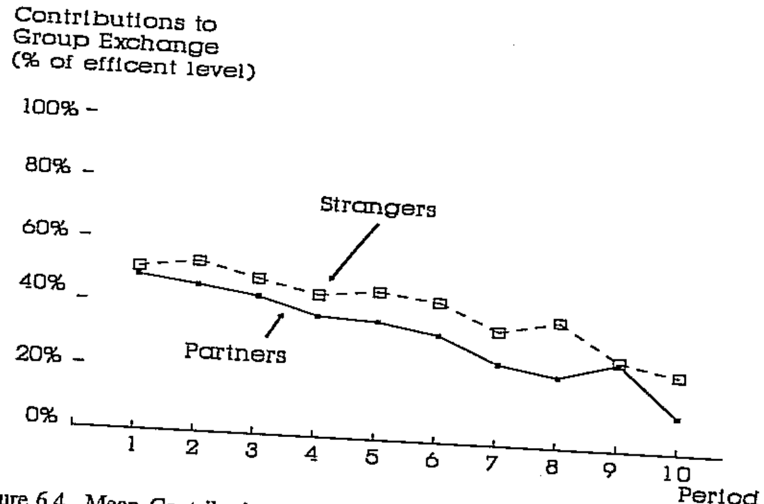

Figure 6.4 Mean Contributions Rates With Regrouping (Strangers) and Without Regrouping (Partners) (Source: Andreoni, 1988)

Experience

Given the well-documented effects of experience in market experiments, one would be surprised if experience did not also affect contributions rates in the voluntary-contributions mechanism. As suggested by the two pairs of sessions illustrated in figure 6.5, contributions to the group exchange do in fact tend to diminish consistently when participants are experienced with the mechanism. Results in figure 6.5 are taken from the Isaac, Walker, and Thomas experiment

7 Andreoni reports that these results are statistically significant. Specifically, the author reports a hi-squared test of the null hypotheses that observations in each treatment are drawn from the same listribution. This hypothesis can be rejected at α>.01.

summarized in figure 6.3. The two panels in the figure represent different parameterizations (both of which satisfy equation 6.3). The left panel illustrates two sessions conducted with groups of four participants and an MPCR = .3. The right panel summarizes two sessions with groups of size ten and an MPCR = .75. Notice that in each case, experienced participants generally contributed less than inexperienced participants. This experience effect was general: Overall, mean contribution rates were 10 percent lower in the four sessions using experienced participants than in the four comparable sessions using inexperienced subjects. Similar experience effects have been observed elsewhere. Perhaps for this reason, the majority of reported experiments use an experienced participant pool.

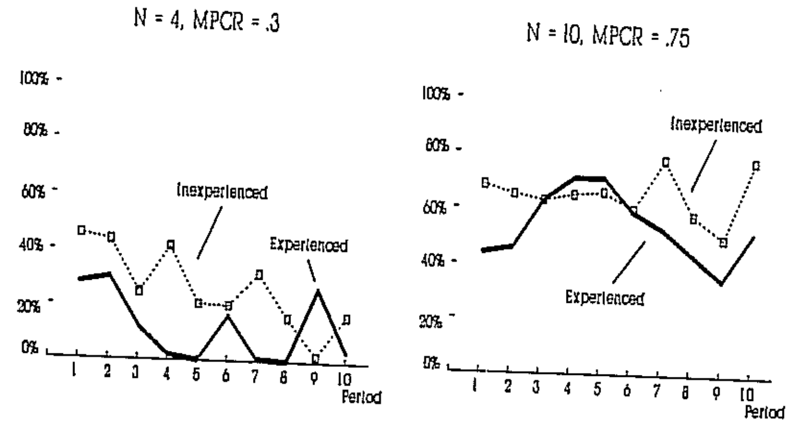

Figure 6.5 Contribution Rates for Two Pairs of Sessions (Source: Isaac, Walker, and Thomas, 1984)

Marginal Per Capita Return versus Group Size Effects

Consider next the effects of group size on contributions to a group exchange. A common conjecture is that incentives to free-ride are magnified as the size of the group increases.[8] One would, for example, expect provision of a pure public good on a national scale, such as defense, to be much more susceptible to free-riding than, say, a voluntary arrangement to clean the bathroom in a shared apartment. One might expect contributions to diminish with increases in the group size, since both efforts to coordinate contributions and attempts to punish free-riding become more

8 For example, Browning and Browning (1989, p. 586) write "As the group size increases, it is more likely that everyone will behave like a free-rider, and the public good will not be provided."

difficult in larger groups. (But note that as the number of people increases, the public good that comes from making an individual contribution to the group exchange is more widely distributed. Therefore, given any particular MPCR, the social benefits of contributing to the group exchange increases with the group size.)

Next consider the possible effects of changes in the MPCR on contributions. Underprovision is always predicted whenever the individual return to a group investment is even slightly less than that available in an alternate private investment. Nevertheless, the decision to allocate resources to the group exchange may be determined in large part by quantitative differences in the costs of contributing. A higher MPCR reduces the cost of contributing to the group exchange and as a result may increase contributions.

Although stark differences in both the group size and the MPCR may occur in natural contexts, these effects are difficult if not impossible to isolate. Instances where two different-sized groups fund the same project are hard to find. Even more problematic is $V'(\Sigma x_j)$, which is difficult to observe as it depends on private preferences.

The relative effect of these alternative motivations for free-riding, however, can be directly observed in the laboratory. Isaac and Walker (1988a) report the results of a particularly well-designed experiment conducted to distinguish group size and MPCR effects for relatively small groups (sizes four and ten), and for large changes in the MPCR (rates of .30 and .75). The design consisted of four treatment cells, one for each of the group size/MPCR combinations. The authors conducted twelve sessions, six sessions using four-person groups, and an additional six using ten-person groups. Each session consisted of two ten-period decision sequences under standard procedures. One of the sequences in each session was conducted under the high MPCR (.75) condition, and the other under the low MPCR (.30) condition. To control for possible sequencing effects, the order of the high and low MPCR treatments was varied across sessions, in a balanced manner.

The left panel of figure 6.6 summarizes the results of this experiment. Labels in the panel identify treatments by group size and the MPCR rate. The label *10L*, for example, represents mean contributions for the six sequences in the ten-person, low-MPCR condition. The MPCR effect clearly dominates the group-size effect: the *10L* and *4L* lines uniformly lie below the *10H* and *4H* lines, indicating that mean contribution rates in the low-MPCR condition are consistently below those in the high MPCR condition, independent of group size. In fact, if there is any group effect at all, it is opposite to that expected by the conventional wisdom. While there is little difference in contribution rates for the small and large groups in the high-MPCR condition, the *4L* line lies considerably below the *10L* line, suggesting that underprovision of the public good may be a more significant problem for small groups than for large groups.

The relationship among MPCR, group size, and contributions to a group exchange was further explored by Isaac, Walker, and Williams (1991), who

examined contribution rates for much larger groups. The results of three forty-person sessions in the MPCR =.3 treatment are illustrated by the line on the right side of figure 6.6. As is clear from comparison of the left and right panels of figure 6.6, very different performance is observed in larger sessions. The mean contribution rate for the three sessions in the *40L* design are much higher than either the *4L* or the *10L* sessions shown on the left of figure 6.6. Moreover, there is virtually no decay in contributions in the *40L* treatment.[9]

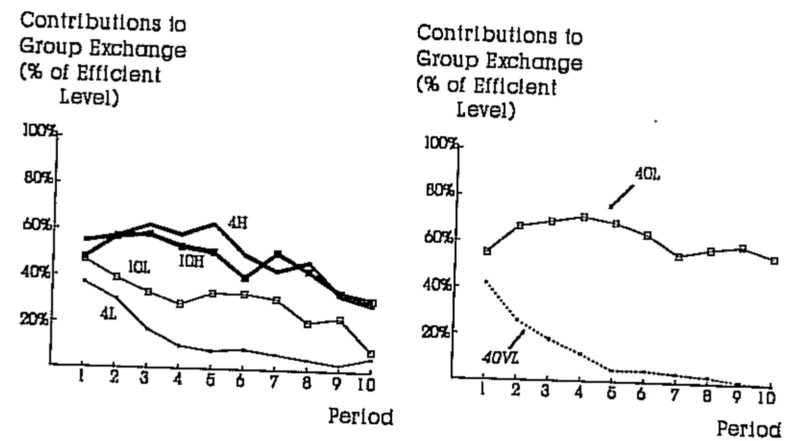

Figure 6.6 Mean Contribution Rates for Four-, Ten-, and Forty-Person Sessions (Sources: Isaac and Walker, 1988a; Isaac, Walker, and Williams, 1991)

One can only conjecture as to why the contributions increase when the size of the group increases, but such conjectures are useful because they can suggest a subsequent experiment. Clearly, it is the case that, other things constant, contributions to the group exchange have a larger effect as the size of the group increases. Recall again that MPCR = V', and that the marginal social benefits of contributions to the group are $N{\cdot}V'$. Thus, the benefits of concerted action increase linearly with increases in the group size. This is clearly shown in the fourth column of table 6.3, which lists the marginal social benefit of a contribution to the group exchange for $N = \{4, 10, 40\}$.

9 These authors generate very similar results in a series of large-group sessions conducted in a "multisession" variant of the voluntary contributions mechanism, where participants make allocational decisions in sequences lasting a week, and where participants are rewarded in terms of extra-credit points rather than cash. Treatments included changes in the group size (40 and 100 people) and in the MPCR (.3 and .75). For these parameters, both mean contribution rates and the rate of decay in contributions appear invariant. Performance was virtually identical in all cells and closely resembles the results for the forty-person sessions illustrated in the text.

Alternatively, Isaac, Walker, and Williams suggest that the primary explanation of contributions to the group exchange may be the proportion of the group necessary for a *minimal profitable coalition*, that is, the smallest collection of participants for whom the return from contributions to the group exchange exceed the return from investing in the private exchange. Of course, the likelihood of a global coalition probably diminishes with increases in the size of the group. Given an MPCR of .3, a minimum of four people must contribute to the group exchange in order for the return from their collective contributions to exceed the return from investments in the private exchange. (This is because 4 is the smallest integer N for which $.3N > 1$.) Thus, the proportion of participants that must invest in the group exchange in order for contributions to the group exchange to remain profitable diminishes as the group size increases. This observation is summarized in the right-most column of table 6.3, which lists the minimum percent of a group necessary for a profitable coalition of four. Notice that with a group of four, everyone must contribute to the group exchange. But with a group of forty, contributions of only 10 percent of the group are needed for a profitable coalition.

This conjecture is consistent with the results summarized in figure 6.6. Regardless of the treatment, individuals initially contribute about half of their tokens to the group exchange. But decay rates vary with the group size. For example, when MPCR = .3, contribution rates decay rapidly in the *4L* treatment, where profitable coalitions require unanimity. The rate of decay is somewhat slower in groups of size ten, where 40 percent of group members are necessary for a profitable coalition. Decay rates for the large groups are still slower and less distinguishable for the forty-person sessions shown in the right side of the figure, where a minimum successful coalition requires contributions from only 10 percent of the group.

Evidence from an additional forty-person session further supports the hypothesis that contributions rates are affected by the minimal profitable coalition. Consider the bottom row of table 6.3. In this row, it is seen that decreasing the MPCR by a factor of 10, to .03, increases the minimal profitable coalition for a large, forty-person group. With the MPCR the minimal profitable coalition is 85 percent of the group (since 34 is the smallest integer N for which $.03N > 1$). Results of a single session, illustrated by the dotted *40VL* line on the right side of figure 6.6, show dramatic decay in contributions. Results parallel data for the *4L* treatment. Of course, these results are also consistent with an explanation based on the "marginal social benefit" column in table 6.3. These two alternatives could be distinguished with additional experimentation.

Summary

Despite a common and unique game-theoretic prediction, contributions rates in laboratory investigations of the voluntary contributions mechanism vary widely. A variety of determinants affect contributions, in spite of the fact that they are theoretically irrelevant in the sense that they to not affect the Nash equilibrium. Such factors include repetition, experience, and the decreases in the MPCR; all of which increase free-riding.

Table 6.3 Group Size and Minimum Profitable Coalitions

Incentive	MPCR (V')	N	Marginal Social Benefit ($N * V'$)	Minimum Profitable Coalition (percent of group)
L	.3	4	1.2	100%
L	.3	10	3.0	40%
L	.3	40	12.0	10%
VL	.03	40	1.2	85%

Upon further examination, however, the determinants of contribution rates appear less settled, and some interaction effects may be present. For example, it is clear from early studies that both repetition and experience exert a larger effect on performance in smaller groups with low MPCRs. Also, and perhaps somewhat surprisingly, contributions appear to increase as the group size expands, at least for some particular MPCRs.

6.4 Factors That May Alleviate Free-Riding

Despite the variety of environmental factors that affect free-riding, it is clear that the underprovision of public goods presents a significant problem in a fairly wide variety of contexts. A natural line of related inquiry involves consideration of variations in the institutional rules of the voluntary-contributions mechanism that might mitigate the observed underprovision rates. This section discusses two such institutional manipulations: communications and provision points.

The unsettled nature of the experimental literature assessing the various environmental determinants of contributions rates provides a rather unstable backdrop against which the effects of these institutional variations might be evaluated. Nevertheless, experimental analysis can identify factors that increase contribution rates relative to performance in a particular baseline environment where free-riding is predominant. Given the diversity of baseline results, however, the generality of such institutional adjustments remains an open question.