INCENTIVES IN PUBLIC GOODS EXPERIMENTS: IMPLICATIONS FOR THE ENVIRONMENT

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January 2001

Abstract: This paper reports results of an experiment designed to evaluate the effects of externalities by altering the costs and benefits of an investment that corresponds to pollution abatement. In this experiment, a person can make an investment with a private (internal) return that does not cover the investment cost, but with a public (external) return that makes the investment socially optimal. Even in the absence of repeated interactions with the same group, investments are increasing in both internal and external returns. Moreover, investments are essentially identical for two treatments with the same "price," defined to be the ratio of the external benefit to the internal loss from making an investment. Individual forecast data make it clear that many who invest nothing are free riding, and that most who make significant investments do not expect others to reciprocate. Implications for dealing with pollution abatement externalities are discussed.

I. INTRODUCTION

Although the costs associated with pollution abatement are primarily borne by those who invest in such reduction efforts, a major share of the benefits may accrue to others external to this

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decision (for example, communities down-river or down-wind from the one making the investment). If people consider only their own private benefits from such reductions in pollution, then economic theory would predict that inefficiently low levels of pollution abatement. Obviously, the market failure will not be as severe if those incurring the costs of the abatement decision also consider the benefit to others. Experiments have been widely used to investigate the effects of financial incentives on the choices that individuals make. A laboratory experiment in a controlled setting allows one assess the extent to which individuals are affected by their own payoffs and the extent to which they are willing to make sacrifices to help others. This permits an empirical approach to issues that cannot be resolved on the basis of theoretical arguments alone. For example, experiments are an ideal setting in which to investigate choices where an externality (either positive or negative) is involved. This paper reports on an experiment designed to evaluate the effects of such externalities by systematically altering the costs and benefits of the investment that corresponds to pollution abatement.

In this experiment, subjects must choose a level of (costly) investment that benefits not only the person investing but also another person. Even when the cost of the investment is relatively low and the benefit to others high, sub-optimal investment is observed. However, the degree of under-investment (relative to the social optimum) is sensitive to both the internal cost and external benefit of this investment. Moreover, in all sessions more investment is observed than would be the case with individuals who are solely maximizing own earnings.

We use a modified public goods experimental design. Subjects begin with an endowment of "tokens" that can either be kept or invested. Each token that a subject keeps yields a constant monetary return for the subject, and each token that is invested also yields a return, both for that subject and for all others in the group. The value of a token kept is the opportunity cost of investment. The earnings structure in this experiment is designed to simulate the incentive structure of the pollution abatement decision. The sum of both group members' returns from the investment typically exceeds the individual's return from keeping the token, so group earnings are maximized by full investment. From a selfish point of view, however, the net monetary loss from making an investment is the difference between the value of a token that is kept and what the subject earns from a token invested. A positive net loss ensures that the Nash equilibrium is to invest nothing, at least in a one-shot game with no altruistic feelings about others' payoffs. Of course, if one cares about others earnings, this may induce some to invest even in this setup.

Following Carter, Drainville, and Poulin (1992), we decompose the return from a token invested so that the one investing may earn a different return than the others who also benefit. For example, a token, worth 5 cent if it is kept, may yield a return of 4 cents to the subject who makes the investment and a potentially different amount, say 2 cents, to the other person in the group. The net loss from making an investment, therefore, is simply the difference between the private value of the token and the return to the one investing, or 5-cents minus 4-cents = 1cent in this example. By independently varying the internal and external benefits we can analyze how the net cost of investing versus the benefit to others affects investment decisions.[1]

The next section describes the laboratory procedures and experimental design, and the third section provides an overview of the overall data patterns. The final section discusses the implications of this and other public goods experiments for environmental decisions.

II. Experimental Design and Procedures

A total of 130 subjects participated in 13 sessions, at the University of Virginia and the University of South Carolina. Participants were recruited from undergraduate economics and business classes, and none had participated in a previous public goods experiment. All subjects in a session were in the same room, but were visually isolated from other participants by the use of "blinders." Subjects were provided with a written copy of the instructions (see Appendix A), which were read aloud by the experiment monitor.

The procedures implemented in these experiments are based on those used by Isaac and Walker (1988). At the start of each round an individual was endowed with 25 tokens, which could be kept or voluntarily invested in an account that benefits all in the group. A token kept earned a constant return of 5 cents, and a token invested earned a return both to the individual and to another participant, with whom this person was matched. Table 1 shows the value of a token invested, both

[1] In the standard public goods experiment, the internal and external returns are identical. The“marginal per capita return” or MPCR, is calculated as the (common) benefit of an investment divided by the value of a token kept. Thus the standard treatment change in the MPCR with alter both the internal and external returns together.

to the investor and the other participant, in each of our five treatments. The *internal return* is the value of the token invested (2-cents or 4-cents), relative to the cost of the investment (5-cents in each of our treatments), to the person investing the token. For example, when a token invested earns 2-cents to the person investing, this corresponds to an internal return of 0.4, which is calculated as the 2-cent "internal" payoff divided by the 5-cent opportunity cost of investing the token. The *external return* is the relative value of the investment to the other person (2-cents, 4-cents, 6-cents, or 12-cents). Therefore, the external returns are 0.4, 0.8, 1.2, and 2.4, respectively. For each of the five treatments shown in Table 1, one session was conducted at the University of South Carolina (with the exception of the fourth row, in which only one session was conducted at the University of Virginia), and all remaining sessions were conducted at the University of Virginia. Individual data for all

Table 1. Experimental Design

Session Numbers	Earnings from a Token Kept	Own Earnings from a Token Invested (internal return)	Other's Earnings from a Token Invested (external return)	Number of Participants
1, 2, 3	5 cents	4 cents (0.8)	2 cents (0.4)	30
4, 5, 6	5 cents	4 cents (0.8)	4 cents (0.8)	30
7, 8, 9	5 cents	4 cents (0.8)	6 cents (1.2)	30
10	5 cents	4 cents (0.8)	12 cents (2.4)	10
11, 12, 13	5 cents	2 cents (0.4)	6 cents (1.2)	30

sessions are reported in Appendix C.

Notice that the value of a token kept (5 cents) is greater than the individual's return from a token invested (2-cents or 4-cents) in all treatments. Thus, the single-round dominant strategy is for each subject to invest nothing. However, it is also the case that the sum of the own and other's earnings from a token invested is greater than the 5-cent value of a token kept. Thus, investing fully would maximize group earnings in all treatments.

At the beginning of each decision period, each person wrote their own investment decision (which was any number of tokens from 0 through 25) on a "record sheet." Then all record sheets were collected and subjects were paired according to a pre-determined schedule of matchings. The other participant's investment was written on the individual's record sheet, earnings were calculated, and record sheets were returned. Each person then made a decision for the next round and a new pairing was implemented. This process was repeated for nine rounds. There were 10 subjects in each session, and pairings were determined so that no one was ever matched with the same person more than once. Participants were told that the other person's identification number would be written on their record sheet so they could observe that there were no repeated matchings. This was done to reduce incentives for "signaling" with high investments in order to encourage the same person to reciprocate in a later round.

Each person knew the number of rounds, their own and others' token endowments in each round, and how all payoffs were calculated, i.e. their own and others' earnings from tokens kept or invested. Prior to the start of each round, subjects could see on their record sheet the number of tokens invested by the other participants with whom they were matched in the previous rounds, and their own earnings in previous rounds.

After record sheets were collected for round 9, subjects were asked to forecast the investment decision of the person with whom they would be matched in the current round.[2] Instructions for this are presented in Appendix B. Subjects were paid a small reward based on the accuracy of this forecast, calculated as 200 cents less the squared deviation of their forecast from the other's actual investment. This forecast was elicited only after subjects had entered their last investment decision, to ensure that their decisions were not affected by the forecasting question.

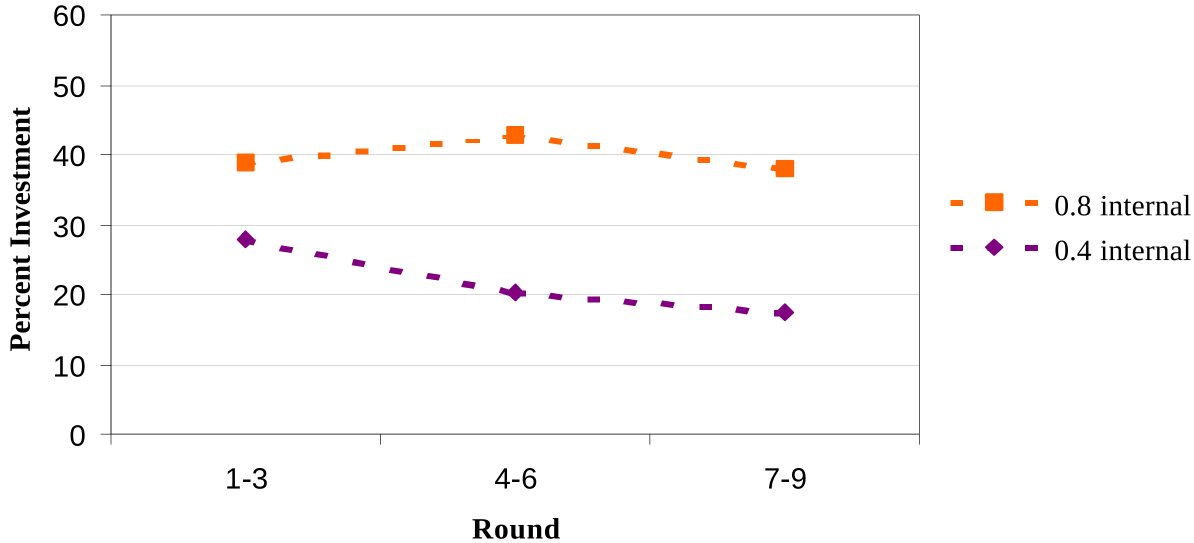
Participants were paid, in cash, the sum of their earnings from the nine decision-making rounds, their forecasting reward, and a $6 participation fee. Earnings ranged from about $14 to $26. Sessions lasted no more than 90 minutes, including subject payment.

[2] No forecast was elicited in three sessions held at the University of Virginia (those labeled sessions 4, 9, and 13).

III. BEHAVIOR

Overall, the percentage of tokens invested follows a similar pattern to that typically observed in public goods experiments. Initial investments are between 30 and 60 percent of the aggregate endowment, and substantial levels of investment are observed in the last round. Moreover, investments generally decline over time in most of our treatments. These similarities with previous public goods experiments are interesting to note given two differences in our design relative to other studies: we restrict our attention to groups of size two, and subjects are never paired with the same

Figure 1. The Effect of a Change in Internal Return (0.4 versus 0.8), Holding External Return Constant at 1.2



subject more than once.[3]

Figure 1 shows the effect of a change in internal return (from 0.4 to 0.8) holding the external return constant at 1.2. This figure shows a time-series of the investment decisions (averaged across

[3] Andreoni (1988) and others, including Carter et al. (1992), conducted experiments in which subjects never participated in the same *group* more than once. However, the group composition was determined by a new random matching in each round and there was a high probability that one would play against some group members more than one time. In Andreoni's study, for example, 20 subjects in a session played in groups of size five for 10 repetitions. Therefore it was certain that they would meet at least some participants more than one time.

all three groups in each treatment) in the early rounds, middle rounds, and late rounds of the experiment. Clearly, increasing the internal return (which results in a decrease in the net cost of investing) has a substantial effect on investment decisions. This effect is noticeable in the early rounds of the experiment, and becomes accentuated in the late rounds after investment choices in the 0.4 treatment declined by about 30 percent from their initial level. In the last half of the experiment (rounds six through nine), about twice as many tokens are invested in the high internal return treatment as in the low internal return treatment. This is shown in Table 2, which presents summary statistics for individual investments in the last four rounds of each of our treatments.[4] This internal effect is significant at only the ten percent level, using a Mann-Whitney test, since there are only three independent observations (sessions) in each treatment. (The session averages for the final three rounds are 0.4, 5.5, and 7.2 tokens for the low internal return treatment, and are 6.3, 10.3, and 11.8 tokens for the high internal return treatment.)

Table 2. Summary of Individual Investment Choices
(number of tokens invested out of an endowment of 25, last 4 rounds)

	mean	median	std. dev	observations
internal = .8 external = .4	5.00	2	6.77	120
internal = .8 external = .8	7.83	5	8.68	120
internal = .8 external = 1.2	9.99	5	10.96	120
internal = .8 external = 2.4	11.23	5	10.97	40
internal = .4 external = 1.2	4.43	0	6.69	120

We next consider the effect of an increase in the external return (0.4, 0.8, 1.2, and 2.4),

[4] In early rounds of experimental sessions investment choices display a lot of noise and there is some indication that subjects experiment with their decisions. Therefore we restrict our attention to the final rounds of a session.

holding constant the net cost of investing (as measured by the internal return). Figure 2 shows the investment averages in these four treatments, in the early, middle, and late rounds. These results provide some evidence of altruism in subjects' investment decisions. With the internal return from investing held constant at 0.8, investment choices increase with an increase in external return. Although early-round investments for the middle two treatments (external returns of 0.8 and 1.2) are reversed, the treatment averages are lined up in the predicted order (at about 20, 30, 40, and 50 percent) by the final rounds. This effect is significant at the 5 percent level, using the Jonckheere test for ordered alternatives. (To test for significance, we use the three treatments where we have three independent observations each.) If this behavior is due to altruism, it is not of the warm-glow variety (defined as increased utility from the act of giving, rather than from what the other receives) because it is responsive to the external return. But neither are subjects acting as pure altruists, i.e. they do not behave in a way to maximize the other's earnings. Other-regarding behavior is more common in our data when the benefit to others of investing increases, holding constant the private cost of the investment. Thus we see a type of price-sensitive or *economic* altruism.

Figure 2. The Effect of a Change in External Return (0.4 through 2.4), Holding Internal Return Constant at 0.8

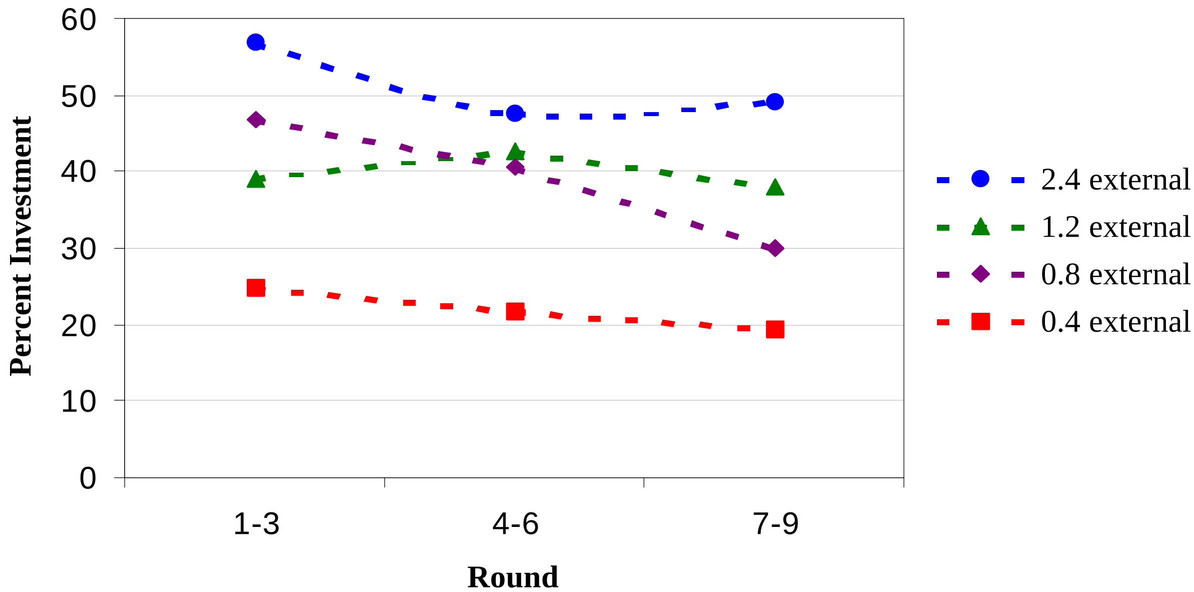
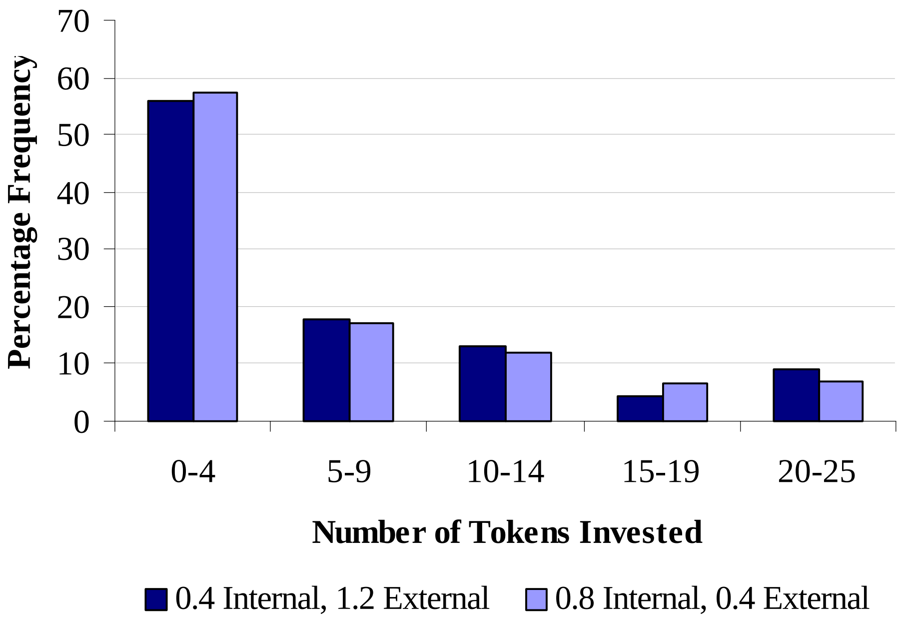
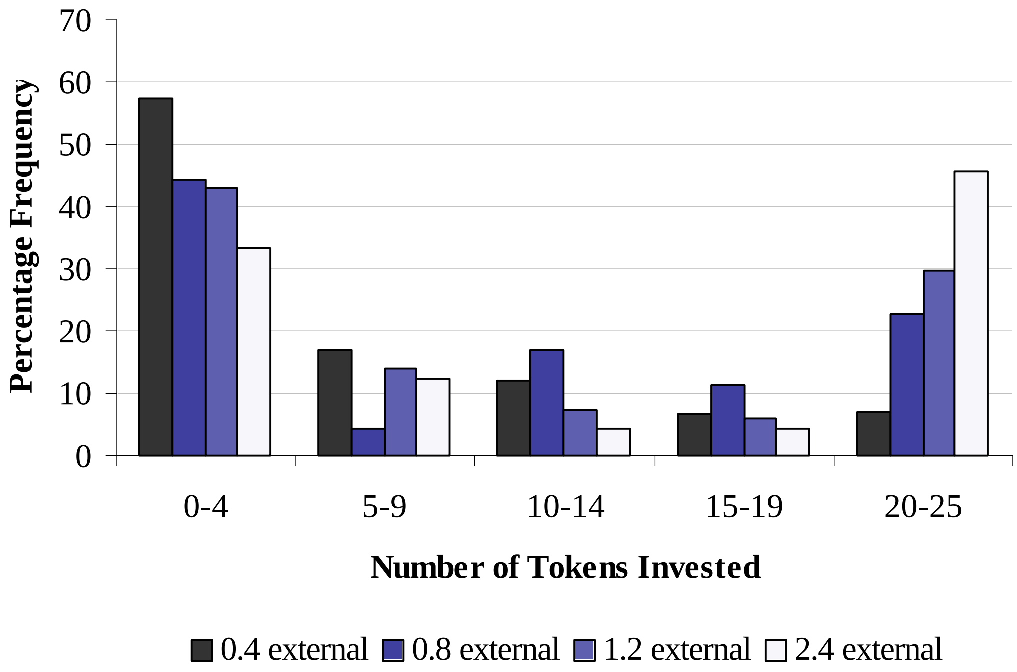


Figure 3. Choice Frequency: Two Treatments with Constant "Price"



If we define the "price" of investing a token as the benefit the other receives relative to the net cost of investing, two of our treatments have an identical price of investing. In the first line of Table 2 (internal = 0.8, external = 0.4), the other person receives 2-cents at a net-cost to the investor of 1-cent (the 5-cent opportunity cost of the token less the 4-cent return from investing the token). Therefore, the price of investing a token in this treatment is 2, which is the ratio of the benefit to the other person (2-cents) to the net-cost of investing (1-cent). Similarly, the last treatment in Table 2 (internal = 0.4, external = 1.2) also has a price of 2, since the benefit to the other person is 6-cents, and the net cost of investing is 3-cents. Notice in the second column of Table 2, the mean investments in these two treatments are quite close (5.0 versus 4.43). The similarity in investment decisions is even more dramatic when you compare the distribution of *individual* investment decisions over all rounds of the experiment. Figure 3 shows histograms of individual investment decisions in both of these treatments. Not only are the mean investment decisions quite close, the distribution of individual decisions are virtually identical.

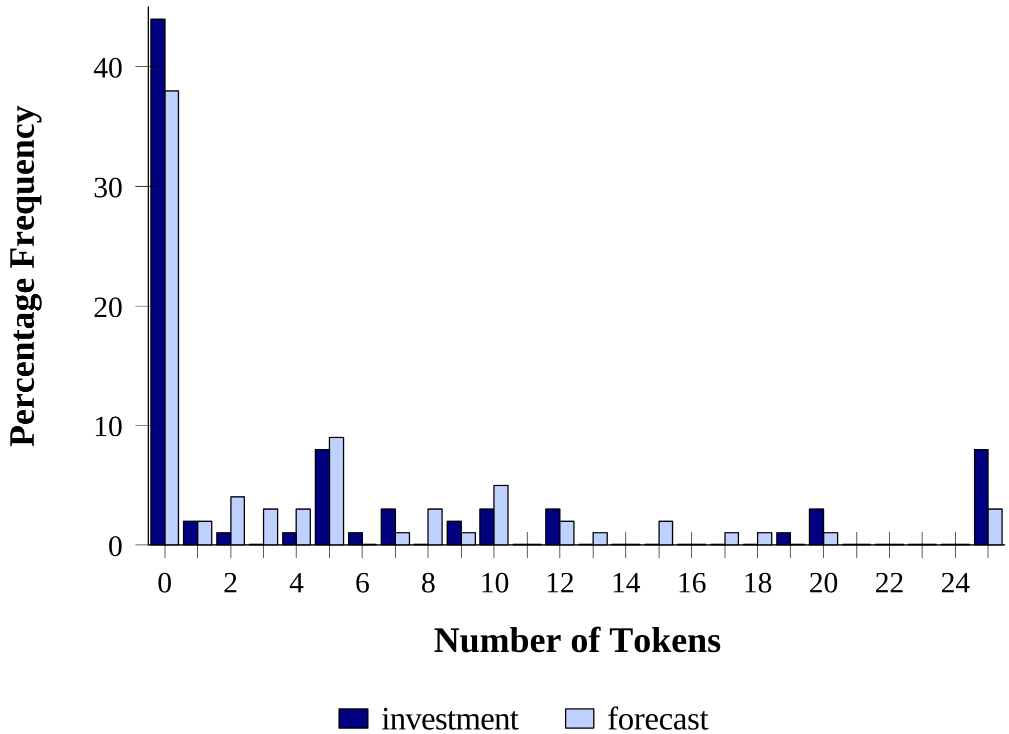
Figure 4. Choice Frequency: Change in External Return



As these histograms suggest, the average investment choices reported above mask a notable feature of the data from these experiments: many individual investments are at or near the extremes of the distribution, and not in the middle as the mean would indicate. However, it is also the case that the treatment affects at which extreme the individual investment decisions are located. This is supported by Figure 4, which presents histograms of individual investments in each of the first four treatments in Table 2. As the external return increases, the percentage of decisions that are at or near full investment (in the 20 - 25 token range) increases dramatically. Just 7.5 percent of observations are in this interval when the external return is 0.4, compared with 42.5 percent when the external return is 2.4.

Although more than half of all investment decisions fall in the extreme intervals containing either zero or full investment, many choices involve "splitting" (keeping only a portion of the endowment and investing the rest). Appendix D presents a formal model of investment behavior that incorporates altruism and error into the decision-making process. In this model, altruism is measured by incorporating the external benefit that the other person receives from an investment into the individual's utility function. Incorporating noisy decision-making accounts for the "U-shaped" distribution of investment decisions, with the majority of decisions located at the upper or lower bounds (depending on the treatment), which represent "optimal" decisions from a theoretic point of view.

Figure 5. Frequency Distribution of Round 9 Investment Choices and Forecast of Others' Choice



The final aspect individual behavior to consider is how the investment choice depends on what the other person is expected to do. If a person invests only because the other is expected to invest a similar number of tokens (perfect reciprocity), then there would be a high correlation between investment decisions and forecasts. Recall such forecasts were elicited (without prior warning) *after* everyone had made a round 9 investment decision (the final choice in the experiment). Although they had seen eight other decisions at this point, they had never before been matched with the person whose investment choice they were forecasting. Figure 5 shows the frequency distribution of the round 9 investments and forecasts, which are remarkably similar. However, these aggregate frequencies do not address the issue of a correlation between each person's investment and that person's forecast of what the person with whom they were matched would do.

Figure 6. Individual Investments Matched with Forecasts

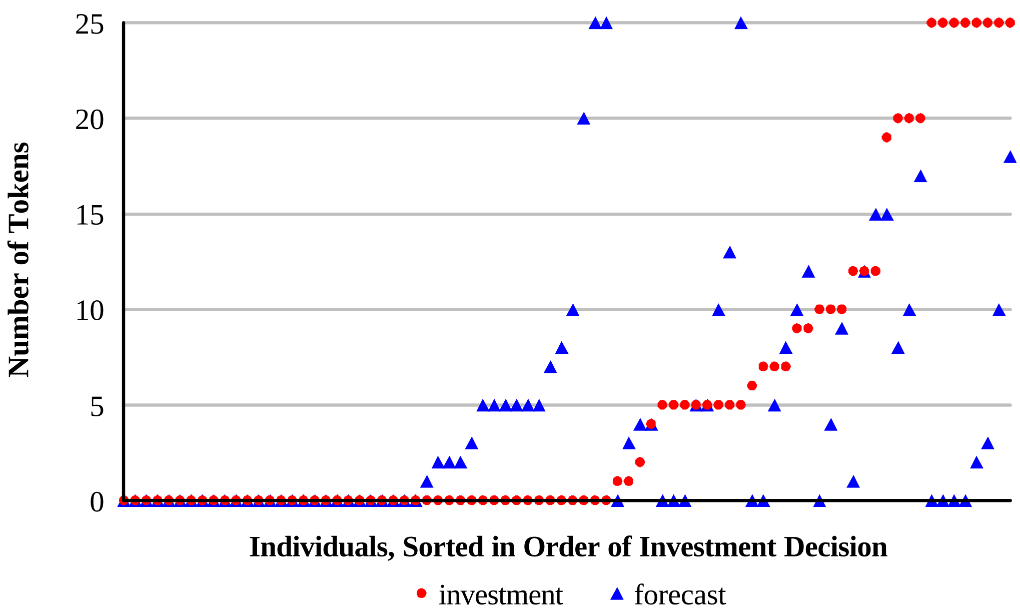


Figure 6 shows individual forecasts and investments, where the individuals are sorted from left to right in order of their investment level. Each person's investment decision and forecast are shown together in a single column. This figure shows the correlation between one's decision and one's expectation, but does not reflect the accuracy of these forecasts. First consider those who invested nothing, i.e. those on the left half of the graph. Of these, about 40 percent were conscious free riders, anticipating that the others would make positive investments. You can see these people as dots at zero tokens invested; the triangles representing their forecast of the other's investment choices are above their zero-investment decisions for nearly half of this group of subjects. Of those who invested 5 or more tokens, on the right half of the graph, about two-thirds were expecting the other person to make a *lower* investment (the triangles for these subjects are below the dot-investment marker). This pattern is universal among those who invested all 25 tokens. Therefore, the majority of those investing did so with no expectation that this investment would be reciprocated.

IV. Conclusions and Implications

This paper reports the results of an experiment in which individuals are given the opportunity to invest in a good that provides both a private benefit to the person investing, and also an external benefit to another person. This setup simulates one of the key features of many environmental cleanup problems: the costs of the cleanup are borne by those investing in technologies designed to reduce pollution or by those undertaking efforts to cleanup existing pollution. However, the benefits are enjoyed not only by those investing in the reduction efforts, but also by others external to this decision (those who are "downstream" or "downwind" of the cleanup efforts, for example). Although economic theory predicts an inefficiently low level of investment in these cleanup efforts will result, if those investing consider not only their own private costs and benefits, but also the benefits enjoyed by others, the degree of market failure may be mitigated.

The data provide evidence that investments are correlated with changes in the external return, holding the internal return constant, and are correlated with the internal return, holding the external return constant. These effects supports the notion of *economic altruism*, i.e. that people are more likely to take actions that raise others' payoffs when the ratio of the benefit to others to the private net cost of investment is relatively high. Moreover, the frequency distributions of investments are virtually identical for two treatments with internal and external returns that are configured to hold constant this price ratio (of external benefit to net cost). The response to treatment effects is variable across subjects and over time for the same subject, and in an appendix we incorporate this noise by using a logit probabilistic choice rule to determine investment probabilities.

Taken together these results provide support for the standard view that individuals (or communities) will not fully consider the benefits to others when choosing the level of resources to devote to cleanup efforts. However, their choices may be sensitive to the cost of undertaking this investment or the amount others stand to benefit. These conclusions should be interpreted with a degree of caution, however. The experiment was conducted in a very stylized setting in order to cleanly address the relative importance of net personal gain and external benefit. Certainly, further experiments in a setting that more closely resembles environmental cleanup decisions are in order. For example, future experiments might incorporate groups making decisions (perhaps in an electoral or referendum-based process). Moreover, it would be instructive to implement heterogeneity into the payoff structure, both in terms of the potential costs and benefits of investment choices. Finally, it would be interesting to conduct experiments in which a real environmental good is provided (for example, subjects would pay to reduce noise levels, or invest in local recycling efforts). The advantage to this is that it adds realistic context, although at the cost of some laboratory control. This is a fruitful area of research that can nicely supplement the more controlled parallel laboratory studies.

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Appendix A: Instructions

You are going to take part in an experimental study of decision making. At this time, you will be given $6 for coming on time. All the money that you earn after this will be yours to keep, and your earnings will be paid to you in cash at the end of today's experiment. We will start by reading the instructions, and then you will have the opportunity to ask questions about the procedures.

Your Decision

The experiment consists of 9 rounds. In each round you will make a decision. For each decision, you will be paired with *one* other participant. Your earnings will depend upon the decisions that you make and the decisions that the other participant makes. You will be paired with a *different* person in each round. You will never be paired with the same person twice.

In every round you will each have 25 tokens. You must choose how many of these tokens you wish to keep and how many tokens you wish to invest. The amount of money you earn in a round depends on how many tokens you keep, how many tokens you invest, and how many tokens are invested by the other participant who is matched with you. You can invest any number of your tokens, from 0 tokens through 25 tokens, and the balance is what you keep.

You will earn 5 cents for each token that you keep. For each token that you invest, you will earn 4 cents and the other participant will earn 2 cents. Likewise, you will earn 2 cents for each token the other person invests.

To summarize, your earnings in each round are determined as follows:

your earnings = 5 cents times the number of tokens you keep
+ 4 cents times the number of tokens that you invest
+ 2 cents times the number of tokens the other participant invests.

Recording Your Decision

Each of you should examine your record sheet, which is the last page attached to these instructions. Your identification number is written on the top-right part of this sheet. At the beginning of each round, you will decide how many tokens you wish to invest and how many you wish to keep. You will begin by writing down in Column 2 how many tokens you wish to invest in round 1 (any number of tokens from 0 through 25). The remaining tokens, 25 minus the number you invest, is the number of tokens you keep. We will enter this number for you in Column 3.

After you make your decision for round 1, we will collect all record sheets. Then we will match you with another person. After this, we will write the other's investment decision on your record sheet (and your investment decision on the other participant's record sheet), record your earnings, and return the record sheet to you. Then you will make and record your decision for round 2, we will collect all record sheets, match you with a *different* participant, write the other's decision on your record sheet, and return it to you. This same process will be repeated for a total of 9 rounds. Remember, you will be matched with a different person in *every* round. We will write the other participant's identification number in Column 6 of your record sheet so you can see that you are never matched with the same person more than once.

Summary

To begin, participants make and record their decisions by writing the number of tokens they wish to invest in Column 2 of their record sheet. Then the record sheets are collected and participants are matched. Once the matching is done, we will enter the number of tokens you keep (25 minus the number you invest) in Column 3, and then record the other's investment decision in Column 7. These decisions determine each person's earnings as described above (you will earn 5 cents for each token you keep, you will earn 4 cents for each token that you invest, and 2 cents for each token that the other person invests). We will write earnings information on the record sheets and return them. Then participants make and record their decisions for the next round. Note that a new matching is conducted for each round.

Final Remarks

At the end of today's session, we will pay to you, privately in cash, the amount that you have earned. You have already received the $6 participation payment. Therefore, if you earn an amount $X during the exercise that follows, you will receive a total amount of $6.00 + $X. Your earnings are your own business and you do not have to discuss them with anyone.

During the experiment, you are not permitted to speak or communicate with the other participants. If you have a question while the experiment is going on, please raise your hand and one of us will come to your desk to answer it. At this time, do you have any questions about the instructions or procedures? If you have a question, please raise your hand and one of us will come to your seat to answer it.

Appendix B: Round 9 Forecast Instructions

Part B.

Please answer the following question while we calculate your earnings.

How many tokens do you think the person you were matched with in this round (round 9) invested?
____

Your earnings from this question will be based on how close you are to the other person's actual investment. Your earnings will be calculated as:

your earnings = \$2 - (your answer - the other's investment)^2

If this is a negative number, your earnings from this part of the experiment will be zero.

If this is a positive number, we will add this amount to your experiment earnings.

Your earnings (in cents) =

200 - [your answer - other's investment]^2

= 200 -

Your earnings from Part B are: ______________

We will add this amount to your earnings from part A (your earnings in rounds 1 through 9) to determine your total earnings for this experiment.

1. Your Earnings from Part A:

2. Your Earnings from Part B:

Your Total Earnings (line 1 + line 2):

Appendix C: Individual Decisions

Key: number of tokens the subject invested
(number of tokens other subject invested)

Session 1: Internal Return = 0.8, External Return = 0.4, University of Virginia

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9	subject 10
round 1	0	0	10	17	0	8	25	17	5	0
	(0)	(0)	(17)	(10)	(8)	(0)	(17)	(25)	(0)	(5)
round 2	0	0	10	12	0	8	19	14	0	0
	(10)	(0)	(0)	(19)	(0)	(0)	(12)	(0)	(8)	(14)
round 3	0	0	5	17	0	0	0	0	2	0
	(0)	(2)	(0)	(0)	(5)	(0)	(0)	(0)	(0)	(17)
round 4	0	0	0	2	0	0	0	2	2	0
	(0)	(2)	(2)	(0)	(0)	(2)	(0)	(0)	(0)	(0)
round 5	0	0	0	0	0	0	25	20	0	0
	(0)	(0)	(0)	(0)	(0)	(25)	(0)	(0)	(20)	(0)
round 6	0	0	0	10	0	2	0	15	8	0
	(0)	(2)	(0)	(15)	(0)	(0)	(8)	(10)	(0)	(0)
round 7	0	0	0	10	0	2	9	10	3	0
	(10)	(10)	(2)	(0)	(3)	(0)	(0)	(0)	(0)	(9)
round 8	0	0	0	0	0	1	9	13	0	0
	(0)	(9)	(13)	(0)	(0)	(0)	(0)	(0)	(0)	(1)
round 9	0	0	0	0	0	1	0	12	0	0
	(1)	(0)	(0)	(0)	(12)	(0)	(0)	(0)	(0)	(0)
round 9 forecast	3	5	0	0	0	0	0	0	1	0

Session 2: Internal Return = 0.8, External Return = 0.4, University of South Carolina

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9	subject 10
round 1	13	10	5	5	4	8	7	0	0	15
	(10)	(13)	(5)	(5)	(8)	(4)	(0)	(7)	(15)	(0)
round 2	10	12	3	0	3	7	2	5	0	13
	(3)	(3)	(10)	(2)	(12)	(0)	(0)	(13)	(7)	(5)
round 3	12	5	6	4	10	16	0	10	0	10
	(0)	(0)	(10)	(10)	(6)	(10)	(12)	(16)	(5)	(4)
round 4	6	3	5	15	3	15	5	10	0	5
	(5)	(10)	(0)	(15)	(5)	(15)	(3)	(3)	(5)	(6)
round 5	8	4	4	25	20	11	3	7	0	11
	(25)	(4)	(4)	(8)	(11)	(3)	(11)	(0)	(7)	(20)
round 6	15	2	0	20	2	18	4	7	0	9
	(2)	(18)	(9)	(7)	(15)	(2)	(0)	(20)	(4)	(0)
round 7	8	9	2	15	15	4	1	7	0	6
	(7)	(15)	(4)	(9)	(0)	(2)	(6)	(8)	(15)	(1)
round 8	7	10	10	20	10	15	3	15	0	4
	(0)	(3)	(15)	(10)	(20)	(4)	(10)	(10)	(7)	(15)
round 9	12	0	2	20	25	10	6	0	0	5
	(10)	(5)	(6)	(0)	(0)	(12)	(2)	(25)	(20)	(0)
round 9 forecast	12	5	4	8	0	4	0	2	7	5

Key: number of tokens the subject invested
(number of tokens other subject invested)

Session 3: Internal Return = 0.8, External Return = 0.8, University of Virginia

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9	subject 10
round 1	10 (10)	10 (10)	0 (10)	10 (0)	20 (25)	25 (20)	20 (25)	25 (20)	25 (2)	2 (25)
round 2	12 (0)	15 (25)	0 (12)	10 (18)	25 (15)	25 (25)	18 (10)	25 (5)	25 (25)	5 (25)
round 3	10 (20)	20 (25)	0 (0)	10 (0)	0 (0)	25 (25)	20 (10)	25 (25)	25 (20)	0 (10)
round 4	20 (3)	25 (25)	0 (25)	10 (25)	0 (17)	25 (10)	17 (0)	25 (25)	25 (0)	3 (20)
round 5	20 (10)	25 (0)	0 (25)	10 (20)	20 (2)	25 (15)	15 (25)	25 (25)	25 (25)	2 (20)
round 6	20 (0)	0 (25)	0 (0)	10 (25)	0 (20)	25 (0)	15 (25)	25 (10)	25 (15)	0 (0)
round 7	15 (25)	15 (10)	0 (0)	10 (15)	5 (25)	0 (0)	15 (3)	25 (15)	25 (5)	3 (15)
round 8	25 (25)	20 (15)	0 (0)	10 (5)	5 (10)	0 (2)	15 (20)	0 (0)	25 (25)	2 (0)
round 9	0 (1)	15 (0)	0 (15)	10 (25)	25 (0)	1 (0)	15 (0)	0 (25)	25 (10)	0 (15)

Session 4: Internal Return = 0.8, External Return = 0.8, University of South Carolina

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9	subject 10
round 1	10 (15)	15 (10)	4 (15)	15 (4)	5 (5)	5 (5)	10 (5)	5 (10)	10 (5)	5 (10)
round 2	15 (3)	15 (0)	3 (15)	20 (25)	0 (15)	25 (10)	25 (20)	5 (7)	10 (25)	7 (5)
round 3	5 (15)	10 (20)	2 (0)	25 (0)	0 (2)	15 (7)	15 (5)	7 (15)	20 (10)	0 (25)
round 4	0 (2)	25 (8)	5 (15)	25 (10)	0 (5)	10 (25)	5 (0)	8 (25)	15 (5)	2 (0)
round 5	5 (23)	15 (6)	6 (15)	23 (5)	0 (8)	12 (2)	2 (12)	10 (15)	15 (10)	8 (0)
round 6	5 (5)	5 (8)	7 (0)	20 (15)	5 (5)	8 (5)	2 (15)	15 (20)	15 (2)	0 (7)
round 7	20 (17)	10 (0)	8 (5)	0 (10)	25 (10)	5 (8)	2 (1)	17 (20)	10 (25)	1 (2)
round 8	25 (10)	0 (5)	1 (20)	15 (0)	0 (15)	4 (0)	5 (0)	20 (1)	10 (25)	0 (4)
round 9	9 (4)	5 (0)	9 (5)	0 (12)	25 (20)	4 (9)	5 (9)	20 (25)	12 (0)	0 (5)
round 9 forecast	10	10	12	10	2	4	0	17	15	0

Key: number of tokens the subject invested
(number of tokens other subject invested)

Session 5: Internal Return = 0.8, External Return = 1.2, University of Virginia

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9	subject 10
round 1	13	0	25	0	15	0	0	0	0	5
	(0)	(13)	(0)	(25)	(0)	(15)	(0)	(0)	(5)	(0)
round 2	0	25	25	0	20	10	4	10	0	0
	(25)	(20)	(0)	(4)	(25)	(0)	(0)	(0)	(10)	(10)
round 3	10	25	25	0	20	5	6	10	0	5
	(6)	(0)	(20)	(5)	(25)	(10)	(10)	(5)	(25)	(0)
round 4	3	25	25	0	25	5	8	15	0	0
	(0)	(15)	(0)	(5)	(8)	(0)	(25)	(25)	(25)	(3)
round 5	0	25	25	0	25	0	4	25	0	0
	(0)	(25)	(25)	(0)	(0)	(4)	(0)	(0)	(25)	(25)
round 6	25	25	25	5	25	5	9	20	0	0
	(25)	(5)	(0)	(20)	(25)	(25)	(0)	(5)	(9)	(25)
round 7	0	25	25	5	25	10	0	25	0	0
	(25)	(5)	(10)	(25)	(0)	(25)	(0)	(0)	(25)	(0)
round 8	20	25	25	5	25	15	0	15	0	0
	(0)	(0)	(15)	(25)	(5)	(0)	(25)	(25)	(20)	(15)
round 9	0	0	25	5	5	5	0	25	0	0
	(5)	(0)	(0)	(0)	(25)	(0)	(25)	(5)	(5)	(0)
round 9 forecast	0	5	0	25	0	0	0	10	20	5

Session 6: Internal Return = 0.8, External Return = 1.2, University of South Carolina

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9	subject 10
round 1	10	2	7	12	5	7	3	2	12	0
	(2)	(10)	(12)	(7)	(7)	(5)	(2)	(3)	(0)	(12)
round 2	15	4	7	5	15	9	5	0	0	0
	(7)	(15)	(15)	(5)	(4)	(0)	(5)	(0)	(9)	(0)
round 3	5	5	2	6	15	8	6	25	0	0
	(6)	(0)	(15)	(0)	(2)	(25)	(5)	(8)	(5)	(6)
round 4	8	0	1	0	15	10	1	25	0	0
	(0)	(1)	(0)	(8)	(0)	(1)	(10)	(0)	(25)	(15)
round 5	2	2	0	2	15	9	25	25	0	0
	(0)	(25)	(0)	(9)	(25)	(2)	(15)	(2)	(0)	(2)
round 6	0	2	0	0	15	10	25	25	0	0
	(15)	(10)	(0)	(25)	(0)	(2)	(0)	(0)	(25)	(0)
round 7	0	4	0	5	0	10	25	25	0	0
	(25)	(5)	(10)	(4)	(0)	(0)	(0)	(0)	(0)	(25)
round 8	0	0	0	0	25	12	0	25	0	0
	(0)	(0)	(25)	(25)	(0)	(0)	(0)	(0)	(0)	(12)
round 9	5	0	0	7	0	10	10	25	0	0
	(10)	(0)	(10)	(0)	(25)	(5)	(0)	(0)	(7)	(0)
round 9 forecast	5	8	0	8	0	9	0	0	0	1

Key: number of tokens the subject invested
(number of tokens other subject invested)

Session 7: Internal Return = 0.8, External Return = 2.4, University of Virginia

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9	subject 10
round 1	0	15	20	25	12	5	15	25	10	5
	(15)	(0)	(25)	(20)	(5)	(12)	(25)	(15)	(5)	(10)
round 2	0	13	25	25	6	5	25	24	8	20
	(25)	(6)	(0)	(25)	(13)	(8)	(25)	(20)	(5)	(24)
round 3	0	20	20	25	1	5	25	25	2	20
	(25)	(2)	(1)	(20)	(20)	(25)	(0)	(5)	(20)	(25)
round 4	0	2	20	25	0	5	25	25	2	20
	(20)	(25)	(2)	(5)	(25)	(25)	(0)	(2)	(20)	(0)
round 5	0	6	5	24	0	25	25	25	0	20
	(24)	(5)	(6)	(0)	(20)	(25)	(25)	(0)	(25)	(0)
round 6	0	0	5	0	3	25	25	25	1	20
	(3)	(25)	(20)	(25)	(0)	(0)	(1)	(0)	(25)	(5)
round 7	0	25	15	25	1	25	25	25	25	0
	(25)	(25)	(25)	(25)	(25)	(15)	(0)	(0)	(1)	(25)
round 8	0	12	21	20	0	25	25	25	0	0
	(0)	(25)	(25)	(0)	(20)	(0)	(12)	(21)	(0)	(25)
round 9	0	19	0	25	5	0	0	25	0	0
	(0)	(0)	(0)	(0)	(25)	(0)	(0)	(5)	(25)	(19)
round 9 forecast	25	15	0	0	13	0	0	18	2	0

Session 8: Internal Return = 0.8, External Return = 0.4, University of Virginia

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9	subject 10
round 1	5	4	5	10	20	10	9	0	0	5
	(4)	(5)	(10)	(5)	(10)	(20)	(0)	(9)	(5)	(0)
round 2	4	8	0	18	20	5	3	0	0	5
	(0)	(20)	(4)	(3)	(8)	(0)	(18)	(5)	(5)	(0)
round 3	0	12	3	13	15	0	2	0	0	15
	(2)	(0)	(15)	(15)	(3)	(0)	(0)	(0)	(12)	(13)
round 4	2	0	2	7	10	0	0	0	0	25
	(25)	(0)	(0)	(0)	(0)	(7)	(10)	(0)	(2)	(2)
round 5	3	25	1	8	0	0	12	0	0	20
	(8)	(1)	(25)	(3)	(20)	(12)	(0)	(0)	(0)	(0)
round 6	1	1	1	4	0	5	21	0	0	20
	(0)	(5)	(20)	(0)	(1)	(1)	(0)	(4)	(21)	(1)
round 7	6	3	0	1	5	0	4	0	0	25
	(0)	(1)	(0)	(3)	(0)	(0)	(25)	(6)	(5)	(4)
round 8	2	5	1	2	0	0	5	0	0	25
	(0)	(5)	(0)	(0)	(2)	(25)	(5)	(1)	(2)	(4)
round 9	0	7	0	1	0	0	7	0	0	25
	(0)	(25)	(7)	(0)	(0)	(0)	(0)	(0)	(1)	(7)
round 9 forecast	0	5	0	3	0	0	0	0	0	3

Key: number of tokens the subject invested
(number of tokens other subject invested)

Session 9: Internal Return = 0.8, External Return = 0.8, University of Virginia

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9	subject 10
round 1	15	5	0	0	10	12	10	15	24	10
	(5)	(15)	(0)	(0)	(12)	(10)	(15)	(10)	(10)	(24)
round 2	20	3	0	10	8	18	10	25	0	15
	(0)	(8)	(20)	(10)	(3)	(0)	(10)	(15)	(18)	(25)
round 3	15	3	5	15	12	0	10	25	0	10
	(10)	(0)	(12)	(10)	(5)	(25)	(15)	(0)	(3)	(15)
round 4	0	0	10	5	10	0	10	0	4	10
	(10)	(0)	(4)	(0)	(10)	(5)	(10)	(0)	(10)	(0)
round 5	20	0	14	10	25	0	10	0	5	7
	(10)	(14)	(0)	(20)	(7)	(10)	(0)	(5)	(0)	(25)
round 6	10	0	20	15	0	0	5	0	5	10
	(0)	(0)	(10)	(0)	(10)	(0)	(5)	(15)	(5)	(20)
round 7	0	0	20	10	5	0	0	0	5	10
	(0)	(10)	(0)	(0)	(5)	(20)	(10)	(0)	(5)	(0)
round 8	0	0	20	0	0	0	0	0	10	0
	(10)	(0)	(0)	(0)	(0)	(0)	(0)	(20)	(0)	(0)
round 9	0	0	0	0	20	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(20)	(0)	(0)
round 9 forecast	5	5	0	0	10	2	0	25	0	0

Session 10: Internal Return = 0.8, External Return = 1.2, University of Virginia

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9	subject 10
round 1										
	()	()	()	()	()	()	()	()	()	()
round 2										
	()	()	()	()	()	()	()	()	()	()
round 3										
	()	()	()	()	()	()	()	()	()	()
round 4										
	()	()	()	()	()	()	()	()	()	()
round 5										
	()	()	()	()	()	()	()	()	()	()
round 6										
	()	()	()	()	()	()	()	()	()	()
round 7										
	()	()	()	()	()	()	()	()	()	()
round 8										
	()	()	()	()	()	()	()	()	()	()
round 9										
	()	()	()	()	()	()	()	()	()	()
round 9 forecast										

Appendix D. A Parametric Theory of Altruism with Decision Error

When it is a dominant strategy for selfish players not to invest in a one-shot public goods game, any investment is a type of error. These errors cause data to be dispersed away from the full free-riding outcome, and the degree of dispersion indicates the importance of errors. What is an error becomes more difficult to spot when players have non-selfish preferences, and it is important to resort to formal modeling and estimation in such situations. When individuals care about raising others' payoffs, perhaps because of altruism or because of a sense of obligation, we can model preferences as including own and others' earnings. The simplest model of altruism is a linear one, in which a person's utility is modeled as their own monetary payoff plus the others' monetary payoffs, weighted by an altruism parameter α (see Ledyard, 1995, or Anderson, Goeree, and Holt, 1998). Below we will use the linear model to estimate the effects of error and altruism in the experiments reported in section II.

Altruistic feelings may be non-linear enough so that people are willing to help others to some extent but not too much. Indeed, people who would like to help others who are worse off than themselves may feel neutral or even jealous when others are better off than they are. A natural way to introduce non-linear altruism is to describe an individual's utility as a non-linear function of own and others' earnings. Andreoni and Miller (1997) report some asymmetric pie-sharing experiments in which a person can give up money that is then multiplied by a constant and given to a randomly selected other participant. This is more like a dictator game than a public goods game in the sense that the roles of the donor and the recipient are not symmetric. Nevertheless, there are strong similarities, and Andreoni and Miller (1997) consider Cobb-Douglas and other specifications to explain the observed tendency for individuals to give up money when the conversion rate into others' earnings is high. In addition, we will use a standard logit model of probabilistic choice to introduce some noise into the decision-making process. Roughly speaking this model implies that non-optimal decisions, or errors, have some chance of being made, with the probability of a mistake inversely related to its severity. First, let us introduce some notation.

We will focus on two-person public goods games with a linear payoff structure. Individual token endowments are denoted by ω. Each token not invested in the public good is worth an amount ν cents. An individual *i* who invests x_i tokens to the public good, earns $\nu(\omega-x_i)$ cents for the tokens kept. In addition, each token invested yields m_I cents for the investor and an m_E cents for the other person. Using the terminology presented above, the internal return is m_I/v and the external return is m_E/v. The expected payoff to player *i*, denoted by $\pi_i^e(x_i)$, is: $\pi_i^e(x_i) = \nu(\omega-x_i) + m_I x_i + m_E x_j^e$, where x_j^e

is the expected investment of the other person. Note that the constant marginal values produce linear payoff functions that are maximized at full free riding when $\nu > m_I$, as is the case in all our treatments. The linear altruism model is obtained by replacing $\pi_i^e(x_i)$ by a weighted sum: $u_i(x_i) = \pi_i^e(x_i) + \alpha\, \pi_j^e(x_j^e)$, where the altruism parameter, α, is typically assumed to be between 0 and 1. In a linear altruism model, an individual is willing to give up \$$\alpha$ in order to increase the other's earnings by \$1. With linear altruism and linear payoffs, the resulting utility is linear in x_i, so full investment is optimal if α is large enough to make the coefficient of x_i positive. Full free-riding is optimal if the coefficient of x_i is negative. Of course, the level of α, v, m_E, and m_I determine the magnitude of the payoff error from not choosing an optimal decision of full investment or full free-riding.

Decision errors are introduced via a standard logit probabilistic choice rule, which implies that the choice probabilities are proportional to an exponential function of the expected payoffs

$$P(x_i) = \frac{\exp(u_i(x_i)/\mu)}{\sum_{x=0}^{\omega} \exp(u_i(x)/\mu)}, \tag{1}$$

where the denominator ensures that the probabilities add up to 1. The error parameter, μ, determines the sensitivity of a player's decisions with respect to payoffs. When μ is very large, payoff differences get washed out, and behavior is close to being random. For a small value of μ, however, the decision with the highest payoff is very likely to be selected, i.e. behavior is close to being rational. The particular parameterization in (1), with u_i determined by the linear altruism model, can be used to estimate the effects of error and altruism. The probability that individual i invests $x_{i,t}$ tokens in period t is given by (1), and assuming that the investment choices are independent across players and periods, the likelihood function is simply given by a product of such probabilities. This is an equilibrium model, and therefore we use only use the last 4 periods of data for estimation. Taking the log of the likelihood function the product becomes a sum, so that

$$\log(L) = \sum_{i=1}^{N} \sum_{t=6}^{9} \log(P(x_{i,t})). \tag{2}$$

The estimates of μ and α can be obtained by maximizing the log-likelihood function with respect to these parameters. Table III gives the results for pooled data for nine of the 14 sessions.

Table III. Maximum-Likelihood Estimates

Variable	Pooled Data
μ	5.4 (0.48)
α	0.09 (0.01)
log(L)	-730

From Table III it is clear that the Nash prediction of no error (i.e. $\mu = 0$) can be rejected at very low significance levels, as other studies have found before (see e.g. Palfrey and Prisbrey, 1997, and Anderson, Goeree, and Holt, 1998). The interpretation of the altruism parameter is that a person values a dollar to oneself the same as nine cents for the other. A significant altruism effect is in line with the findings of Anderson, Goeree, and Holt (1998) who estimated an altruism parameter of $\alpha = 0.07$, using data from public goods experiments conducted by Isaac and Walker (1988) and Isaac, Walker, and Williams (1994). In contrast, Palfrey and Prisbrey (1997) estimate a significant warm-glow effect in their data, but find no evidence for (linear) altruism. Since a change in the external return, m_E, has no effect on investments in a model with only warm-glow altruism, our data do not support such a model. Indeed, given the rough correlation between the external return and investments, it is not surprising that we find significant evidence for the presence of altruism.

While linear models may be applicable for some parameter values, it is difficult to imagine that someone willing to give up 12 cents to give someone else a dollar, is also willing to give up $120 to give someone else $1,000. This seems even more unlikely when the other person is already better off. One way to model non-linear tradeoffs between own and other's expected earnings is to specify a non-linear utility function of expected earnings.[5]

[5] Putting expected earnings in arguments of such a function simply means that the rate at which you are willing to trade off your own expected earnings in order to increase another's expected earnings is non-linear. The function implies that only expected earnings matter, i.e. there is no risk aversion. There is no inconsistency in having non-linear altruism and risk neutrality.