An Experimental Examination of the Volunteer's Dilemma

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Abstract

The volunteer's dilemma is an *n*-person, binary-choice game in which a single contributor ("volunteer") is all that is needed for a given benefit to be enjoyed by all players. Examples include casting a politically costly veto or attempting an emergency rescue. The contribution decision is costly, and the symmetric Nash equilibrium involves mixed strategies. These Nash predictions have the intuitive property that the probability of volunteering is a decreasing function of the number of players. There is, however, a surprising feature: the equilibrium probability of obtaining no volunteers is increasing in the number of players and may be quite large (depending on parameters), even as the number of players goes to infinity. These predictions are evaluated with a laboratory experiment. The data show deviations from both Nash and quantal response equilibria, and alternative explanations (e.g. a combination of quantal response and inequity-aversion) are explored.

Note: most of this is from an earlier version that was only based on data from UVA for group sizes of 2, 3, and 6. The power point has the new data.

I. Introduction

A classic paradigm in public economics is the voluntary contributions game in which each person in a group must decide whether to make a costly contribution that provides a benefit to all group members, or whether to "free ride" on others' contributions. In a "provision-point" version of this game, the public benefit is not obtained unless a pre-specified level of contributions is obtained. One curious example of a game with a provision point is found in Poundstone (1992), who describes an announcement that appeared in the October 1984 issue of *Science*. Readers were invited to submit a request either \$20 or \$100, with the understanding that all requested amounts would be paid as long at least 80 percent of the responders only asked for the \$20 payment. If this target were not met, then no payouts would be made. Just prior to the

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publication date, the publisher became concerned about the cost and tried unsuccessfully to get Lloyd's of London to insure against a payout. One staff writer offered to put some of his future salary on line as collateral. In the end, the publisher solicited responses with the stipulation that payoffs would be calculated and announced, but not actually made. The magazine received over 33,000 requests, with about two-thirds being at the $20 level, so a payout would not have been made if this behavior pattern had been observed in a real-payoff setting.

There is a special category of voluntary contributions games where the provision point is that only one contributor or "volunteer" is needed for the pubic good to be obtained. For example, it only takes one person to veto an undesired outcome under unanimity voting, but such vetoes may be politically costly. Similarly, all members of a legislative body may desire a pay raise, but each prefers that one of the others sponsor the bill and incur the political cost. Another example can be found in the behavior of a group of foraging animals in which one of them will occasionally look up and check for a predator. The one who issues an alarm is more likely to attract the attention of the predator. It has been observed that ground squirrels check more frequently when in the presence of kin (Murnighan, Kim, and Metzger, 1993).

The game where only one contribution is needed to provide the group benefit is known as the "volunteer's dilemma" (Diekmann 1985, 1986). Specifically, let V denote the monetary benefit that all N members of a group receive if at least one of them decides to contribute and incur a cost C. If nobody volunteers, then all receive a lower payoff of $L < V$. It is assumed that $C < V - L$, so each person would prefer to volunteer if nobody else does. But if someone else is expected to volunteer, then each of the others would prefer to "free ride." Thus there are many asymmetric equilibria in which one person volunteers and the others do not, but coordinating on such equilibria may be difficult when decisions must be made quickly or simultaneously, as when bystanders must decide whether to rush in and attempt a risky rescue of someone in trouble.

In the volunteer's dilemma with payoffs that satisfy the assumptions made above, there is also a symmetric mixed-strategy Nash equilibrium in which each person volunteers with probability p. Not surprisingly, the equilibrium level of p is a decreasing function of the group size, N. This prediction is consistent with casual observation and is also seen in results from social psychology experiments with a staged "emergency" (Darley and Latane, 1968; Latane and Darley, 1970). This diminished tendency for members of large groups to intervene in staged emergencies has been attributed to a "diffusion of responsibility." Public awareness of this issue was heightened by the failure of anyone to go to the aid of Kitty Genovese who was raped and stabbed to death in 1964 in the courtyard of her apartment complex. Despite the fact that 38 people were watching from their windows, the police were not called until the attack was over. A less tragic outcome occurred when Teresa Saldana, who appeared in the 1982 film *Raging Bull*, was subsequently assaulted by a crazed fan who had come to Los Angeles from Scotland to stalk her. Her screams attracted a group of bystanders, but a man making a bottled water delivery charged in and risked injury or death to hold the assailant down until police arrived. The actress survived and continues with her career.

Even though the probability of volunteering declines with group size, it may be the case that the probability of getting *at least one* volunteer does not decline as the number of potential volunteers increases. This possibility may seem intuitive, but it is at odds with the symmetric Nash equilibrium. For example, if V = \$1.00, C = \$0.20, and L = \$0.20, it will be shown in the next section that the Nash prediction is for the probability of volunteering to decline from ¾ to ½ as the group size increases from 2 to 3. So the chances of getting at least one volunteer goes from $1 - (1 - (3/4))^2 = 0.94$ for $N = 2$ down to $1 - (1 - (1/2))^3 = 0.88$ for $N = 3$. Moreover, as N goes to infinity, the Nash prediction for the probability of getting at least one volunteer falls to 0.75. Franzen (1995) tested this unintuitive prediction for a wide range of group sizes, ranging from 2 to 101, in a laboratory game that was only played once. The volunteer rate fell from about 2/3 for small groups to about half that rate for large groups, and probability of getting at least one volunteer was close to 1 for groups with 10 or more people. Subjects in this experiment completed a questionnaire and received results and monetary payments later by mail, after all responses had been collected and grouped.

There may be a fair amount of "noise" and confusion in a one-shot game, but some noise due to calculation errors and unobserved preference shocks may persist in repeated games with random matching, and the result may be that the probability of getting at least one volunteer might approach 1 for large groups. McKelvey and Palfrey

(1995) proposed a generalization of the Nash equilibrium, the quantal-response equilibrium (QRE), which incorporates such noise effects in an equilibrium framework that requires choice probabilities to be consistent with beliefs. The QRE prediction is that the probability of getting at least one volunteer will approach 1 for sufficiently large groups (Goeree and Holt, 1995). Equilibrium theories should be tested under conditions in which beliefs have had a chance to stabilize, and therefore, this paper will report the results of repeated volunteer's dilemma games with random matching and variations in group size.

Diekmann (1995) noted another unintuitive feature of the mixed-strategy Nash equilibrium in asymmetric versions of the volunteer's dilemma. Recall that each person must be indifferent between their two decisions in order to be willing to randomize, so the expected payoffs for volunteering and not volunteering must be equal. In a two-person game, an increase in one person's volunteer cost will not alter that person's predicted volunteer rate, since any change would cause the *other* person to no longer be indifferent. But the person whose cost has increased must be "induced" back to indifference by lowering the equilibrium volunteer rate of the person whose cost has not changed. Recall the numerical example given above (V = \$1.00, C = \$0.20, L = \$0.20), which produces an Nash volunteer rate of 0.75 with N = 2. It can be shown that a three-fold increase in one person's cost, from \$0.20 to \$0.60, will not alter that person's equilibrium volunteer rate but will reduce the *other person's* rate from 0.75 to 0.25. This absence of an "own-payoff effect" is unintuitive, and such effects have been observed and explained by a quantal-response approach in other some asymmetric 2x2 games with unique mixed-strategy equilibria (Goeree, Holt, and Palfrey, 2003). Diekmann (1995) provides some evidence for own-payoff effects in 2-person volunteer's dilemma games, although the results for 5-person games were more ambiguous. As was the case with the Franzen experiment discussed above, these asymmetric-payoff experiments were done as one-shot games in which subjects filled out questionnaires and received results and payoffs by mail. A second experiment (to be) reported below will focus on the effects of payoff asymmetries in repeated games with random matching, and on whether the behavior patterns can be explained by the Nash equilibrium or its QRE generalization.

A final issue to be addressed is the nature of any biases that might cause volunteer rates to deviate from Nash predictions in systematic patterns. Both Diekmann (1986) and Franzen (1995), for example, reported volunteer rates that were generally in excess of Nash predictions for all group sizes in games administered via a questionnaire. This tendency for excess cooperation might be explained by risk aversion, altruism, or confusion in one-shot games. In contrast, we observe volunteer rates that are too low for low group sizes (2 and 3), and that are slightly above Nash predictions for larger group sizes (6, 9, and 12). A person who volunteers earns less than those who do not, and recent models of inequity aversion (Fehr and Schmidt, 1999) suggest that this earnings differential may reduce volunteer rates. In particular, we will consider a quantal response model with the incorporation of some element of inequity aversion.[1]

II. The Nash Equilibrium

A decision to volunteer results in a sure payoff of $V - C$, and a decision not to volunteer yields the high payoff, V, if at least one other person volunteers. In a symmetric equilibrium, all players volunteer at a rate p, so the probability of getting at least one volunteer decision from the $N - 1$ others is: $1 - (1-p)^{N-1}$. Recall that the payoff if nobody volunteers is L, so the expected payoff from not volunteering is provided on the right side of (1), which equates the expected payoffs for the two decisions:

$$(1) \qquad V - C \;=\; V\left[1-(1-p)^{N-1}\right] \;+\; L(1-p)^{N-1}.$$

Thus the probability of not volunteering is:

$$(2) \qquad 1-p \;=\; \left(\frac{C}{V-L}\right)^{\frac{1}{N-1}}$$

and hence the equilibrium volunteer rate is determined:

[1] See Goeree and Holt (2000) for a QRE analysis of inequity aversion in alternating-offer bargaining games with asymmetric monetary side payments.

(3) $$p = 1 - \left(\frac{C}{V-L}\right)^{\frac{1}{N-1}}.$$

It follows from (3) that the volunteer rate will be decreasing in *N* if $C/(V\text{–}L) < 1$, as assumed.

Next consider the probability that none of the *N* players decides to volunteer, which is $(1 - p)^N$. This probability can be calculated from (2):

(4) $$\text{Pr(no-volunteer outcome)} = (1-p)^N = \left(\frac{C}{V-L}\right)^{\frac{N}{N-1}},$$

which is increasing in *N* when $C < V - L$ as assumed.

III. Procedures

In each session of the experiment, cohorts of subjects participated in 20 consecutive decision periods of the volunteer's dilemma game, with random matching.[2] In the symmetric-payoff design, the benefit to every member of the group if at least one person volunteered was \$1.00 (*V*) and the individual cost of volunteering was \$0.20 (*C*). If there were no volunteers in the group, each participant earned \$0.20 (*L*). Group size (*N*), however, varied across treatments and took one of five values: 2, 3, 6, 9, or 12. These group sizes were chosen because they induce Nash equilibria on both sides of ½. Specifically, as can be seen from equation (3), the Nash equilibrium falls from 0.75 to 0.5 to about 0.25 as the group size increases from 2 to 3 to 6. Three sessions were conducted in each of these three treatments, two at the University of Virginia and one at UCLA.[3] In addition, we used the large lab at UCLA to run a session with 24 participants (4 groups of

[2] Most sessions had one or more unrelated experiments that followed the completion of this experiment but subjects were unaware of this at the time they made the reported decisions.

[3] The eleven sessions took place in the following order: Session 1 (UVA, March 16; 10 subjects, Group Size=2), Session 2 (UVA, March 21; 12 subjects, Group Size=6), Session 3 (UVA, March 22; 12 subjects, Group Size=3), Session 4 (UVA, March 23; 12 subjects, Group Size=6), Session 5 (UVA, March 24; 12 subjects, Group Size=3), Session 6 (UVA, March 29; 12 subjects, Group Size=2), Session 7, (UCLA, June7, 12 subjects, Group Size=2), Session 8 (UCLA, June 7, 12 subjects, Group Size = 3), Session 9 (UCLA, June 7, 24 subjects, Group Size = 6), . Session 10 (UCLA, June 8, 36 subjects, Group Size = 9), Session 11 (UCLA, June 8, 48 subjects, Group Size = 12).

size 6 in each round), a session with 36 participants (4 groups of size 9), and a session with 48 participants (4 groups of size 12).

Upon arrival, participants were seated at visually isolated computer terminals. The software interface used to conduct the experiment can be found on the V*e*conlab website under volunteer's dilemma game (http://veconlab.econ.virginia.edu/vd/vd.htm). Detailed instructions were both displayed on the subjects' screens and read aloud by an experimenter. Neutral terminology was used to avoid any potential bias due to the volunteer's dilemma scenario. Thus, each individual chose whether to "invest" or "not invest," where investment by any member of the group at a cost would provide a benefit to all members of the group, regardless of whether they chose to invest. Subjects were undergraduate students recruited from classes at the University of Virginia and UCLA. Each subject was paid $6 for showing up and any additional earnings from the experiment. Total earnings for the experiment, which lasted approximately 45 minutes, averaged approximately $21 and all participants were paid in cash at the conclusion of the experiment.

IV. Data

The results for all sessions are reported in the tables below. Table 1 displays the average volunteer rates by session, along with treatment averages and Nash predictions. The data for the UCLA sessions are shown in bold type, and it is apparent that there is no obvious subject pool difference. Note that the session averages are ranked inversely with group size, as predicted. The null hypothesis of no group-size effect can be rejected at approximately the 1 percent level, even if attention is restricted to session averages and qualitative rankings.[4]

[4] There are 11! ways that the session averages could be ranked. Of these, there are 8 rankings that are as extreme as what we observed. In particular, there are 6 ways that $N = 2$ sessions can be ranked in the top group, and 6 ways that the N = 3 sessions can be ranked in the middle group, and 6 ways that the N = 2 sessions can be ranked in the bottom group, so there are 6x6x6 = 216 ways that the session averages could be arrayed in a manner that is at least as extreme as what was observed. Under the null hypothesis of no group size effects, all 11! rankings would be equally likely, so the chances of seeing the ranking implied by the top row of Table 1 would be 216/(11!), or about 0.1%. **** redoMore formally, one could use the Jonckherre test, which produces a test statistic of 12, which is the cutoff for a rejection at the 1 percent level of significance (see Siegel and Castellan (1988, p. 216).

Table 1. Volunteer Rates (UCLA Sessions in Italics)

	N = 2 (34 subjects)	N = 3 (36 subjects)	N = 6 (48 subjects)	N = 9 (36 subjects)	N = 12 (48 subjects)
Session Averages.	0.55, 0.51, *0.49*	0.42, 0.38, *0.39*	0.28, 0.20, *0.31*	*0.19*	*0.19*
Overall Average	0.52	0.40	0.28	0.19	0.19
Nash Prediction	0.75	0.50	0.24	0.16	0.12

The averages by treatment, along with Nash predictions, are also plotted in Figure 1. The data averages do not reflect the predicted degree of sensitivity to group size changes.

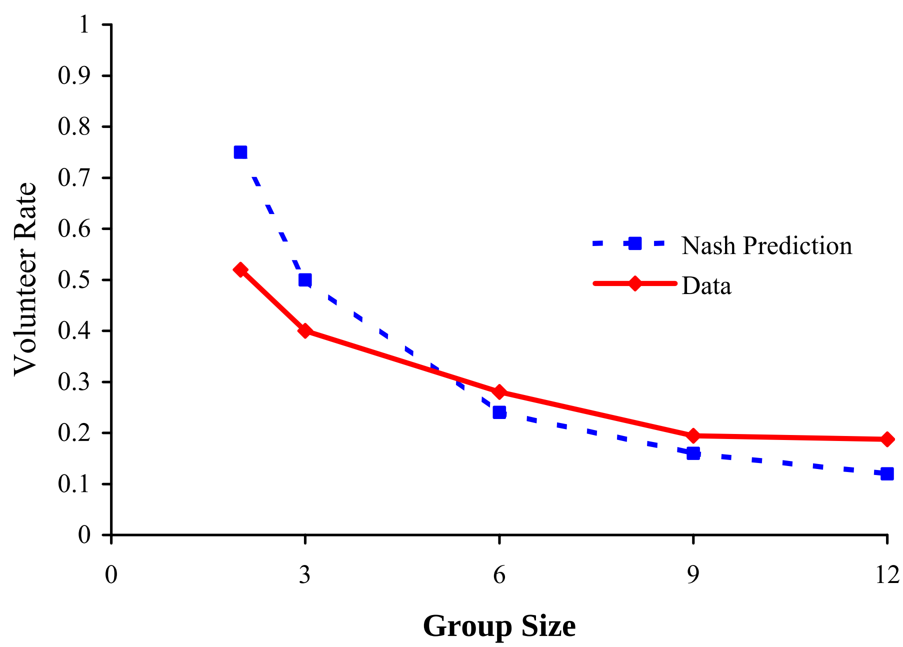

Figure 1. The observed average volunteer probability (solid line) and the volunteer probability predicted by Nash (dashed line).

Instead of ranging from 0.75 to 0.12, as predicted in a symmetric Nash equilibrium, the observed average volunteer rates are much more condensed and range only from 0.55 to 0.19. Moreover, there seems to be some underlying influence that is causing observed probabilities to be lower relative to the Nash prediction for smaller group sizes (2 and 3). This negative influence disappears for the larger group sizes. Later in the paper, we explore several explanations for this pattern including inequity aversion, quantal response equilibrium, and learning.

As noted above, one unintuitive Nash prediction is that the probability that no members of a group volunteer actually increases with group size. The incidence of no-volunteer outcomes is reported in Table 2 for each session, along with Nash predictions and treatment averages, which are also plotted in Figure 2.

Table 2. Rate of No-Volunteer Outcomes (UCLA Sessions in Italics)

	N = 2 (34 subjects)	N = 3 (36 subjects)	N = 6 (48 subjects)	N = 9 (36 subjects)	N = 12 (48 subjects)
Session Averages.	0.20, 0.18, *0.25*	0.21, 0.21, *0.24*	0.13, 0.20, *0.15*	*0.13*	*0.11*
Overall Average	0.21	0.22	0.16	0.13	0.11
Nash Prediction	0.06	0.13	0.19	0.21	0.22

Note that the probability of a no-volunteer outcome does not significantly increase over time, as predicted by the Nash equilibria. In contrast, this probability is decreasing for the larger group sizes, as shown in Figure 2.

V. Noisy Behavior (and Inequity Aversion?)

A standard way to model noisy behavior for simple binary choice decisions is to specify a probabilistic choice function (logit, probit, etc.), which maps expected payoff differences into choice probabilities. In an analysis of a game like the volunteer's dilemma, the expected payoffs themselves depend on beliefs about others' choice. The quantal response equilibrium condition requires that the beliefs be rational in the sense that belief probabilities must equal choice probabilities (McKelvey and Palfrey, 1995). All players volunteer with probability p in a symmetric equilibrium, and the resulting expected payoffs for volunteering and not volunteering are $\pi_v = V - C$ and $\pi_n = V(1 - (1-p)^{N-1}) + L(1-p)^{N-1}$ respectively For estimation purposes, we use a logit function:

(5) $$p = \frac{\exp(\lambda\pi_v)}{\exp(\lambda\pi_v) + \exp(\lambda\pi_n)},$$

where λ is a precision parameter. Recall that π_n is a function of p and N, so (5) is a nonlinear equation that must be solved numerically for p as a function of λ and N. We will denote the solution by $p(\lambda, N)$.[5]

As λ goes to zero, the right side of (5) converges to ½ regardless of payoff differences, which corresponds to the case of perfectly noisy behavior. As λ goes to infinity, it can be shown that the probability of making the best choice goes to 1. One thing to notice about (5) is that the expected payoffs are equal in a mixed-strategy Nash equilibrium, so response determined by (5) in this case is that p = ½. Thus if the Nash equilibrium involves probabilities of ½, the quantal response prediction will also be ½. Moreover, when the Nash equilibrium is above or below ½, the effect of adding noise via a quantal response will pull the prediction towards the midpoint of ½ in these *n*-person

[5] A simple Matlab program that finds the solution is available from the authors on request.

binary-choice games.[6] This "pull" towards the center is clearly not reflected in the data plot for Figure 1, where the downward bias for the N = 2 treatment is not matched by an upward bias for the N=6 treatment, and the data average for the N = 3 is lower than the Nash and QRE prediction of 0.5.

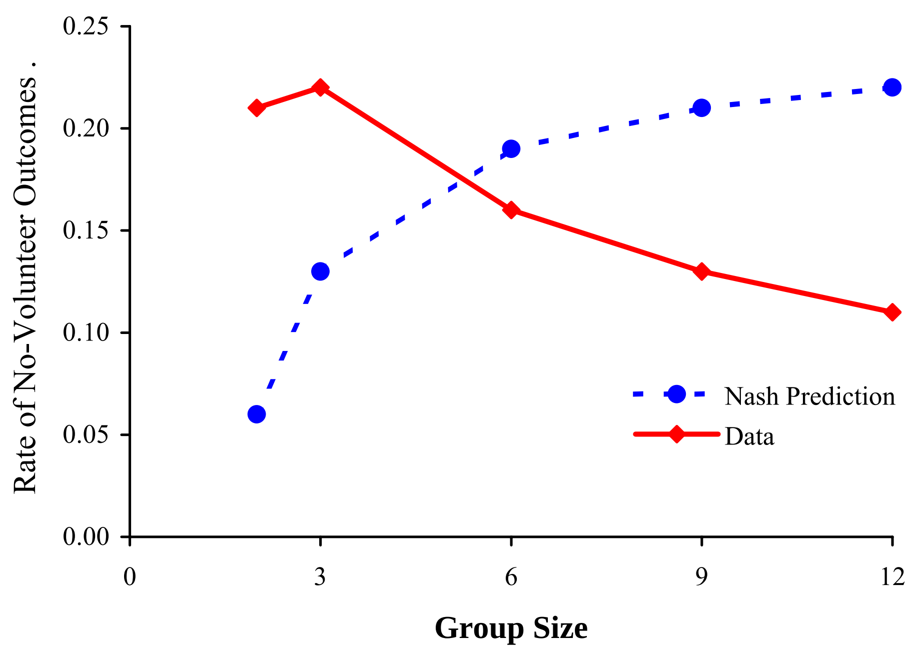

Figure 2. Predicted and Actual Rates of No-Volunteer Outcomes

It follows from these observations that the QRE model will not provide a good fit, at least not without further adjustment. To estimate the model, we specify the likelihood as a function of the QRE solution and the observed numbers of volunteer and no-volunteer decisions for each value of N. The data counts for volunteer decisions are

[6] These results do not depend on the particular logit parametric specification. See Goeree and Holt (2005), who consider a more general case where the shocks to expected payoffs are independently and identically distributed. More precisely, they assume that the difference between the shocks has mean 0 and this difference has a cumulative distribution function with the property that F(0) = ½.

denoted by $v(i)$ for group sizes i = 2, 3, 6, 9, and 12. The corresponding data counts for no-volunteer decisions are n(i). Then the log likelihood function is a constant plus:

$$\text{(6)} \qquad \text{Log Likelihood} = \sum\nolimits_{i=2,3,6,9,12} v(i)\log(p(\lambda,i)) + n(i)\log(1-p(\lambda,i)).$$

At each iteration of the search process, the model must be solved for the quantal response probabilities, p(λ, N).[7] The results are shown in the Quantal Response row of Table 3. It is immediately apparent that the QRE predictions on the right for this row are too high for all group sizes, as compared with the data averages in the bottom row of that column.

*** This table needs to be redone for the new data from UCLA) ***

Table 3. Maximum Likelihood Estimates (Standard Errors) – UVA Data Only

	λ	α	Log Likelihood	QRE Predictions and Data Avg. (N = 2, 3, 6)
Quantal Response	7.4 (1.8)		−923.98	0.65, 0.50, 0.33
QRE with Inequity Aversion	4.8 (1.1)	1.55 (0.25)	−891.66	0.53, 0.39, 0.24
Data Averages				0.53, 0.40, 0.24

When a person volunteers, they earn less than those who do not, and an aversion to this earnings inequity might reduce volunteer rates. Fehr and Schmidt (1999) propose a model in which utility is reduced by an "envy" parameter, α, which is multiplied by the adverse earnings inequity. When there are $N - 1$ other players in a symmetric game, one way to proceed is to multiply α times the expected value of the earnings inequity, which is $(1 - p)$C, since the player who volunteers earns C less than those who do not, and the fraction of the others who do not volunteer is $1 - p$ in equilibrium. In this case, the expected payoff from for a volunteer is adjusted to become: $\pi_v = V - C - \alpha(1 - p)C$. The estimation results for this model are shown in the second row of Table 3. Note that the log likelihood is much higher and the augmented QRE predictions in the far right column

[7] A simple Matlab program that maximizes this likelihood is available in the appendix, and the version included was used to obtain preliminary estimates using only the UVA data. The data counts used are: $v(2) = 233$, $v(3) = 192$, $v(6) = 115$, $n(2) = 207$, $n(3) = 280$, and $n(6) = 365$. Payoffs were entered in dollar amounts: $V = 1.00$, $C = 0.20$, and $L = 0.20$.

match the data averages. The estimate of the envy parameter, α, is greater than 1, which is too high relative to estimates reported by Goeree and Holt (2000) and relative to the parameter values used by Fehr and Schmidt (1999) to explain results of a variety of laboratory experiments.

VII. Conclusion

One extension might be to run a treatment that raises the cost of volunteering so as to increase the earnings inequity between volunteers and those who don't. Another idea is to run some sessions with payoff asymmetries, e.g. 2-person groups with a 50/50 chance of getting increase one player's cost from $0.20 to $0.60. This change does not affect that person's Nash volunteer probability of 0.75, but it reduces the prediction for the other player volunteer rate from 0.75 to 0.25. This kind of asymmetric setup might provide a sharper comparison of QRE and Nash predictions. Another way to go could be to have volunteer costs be drawn from a distribution, so that the Nash equilibrium is a "cut-point" strategy, and to look at the QRE prediction for this setup.

We plan to investigate learning dynamics and the predictions of a steady-state "stochastic learning equilibrium" that produces equilibrium predictions about finite sequences of decisions or "histories."[8] We have also collected demographic data from all participants, which might turn out to be useful in the analysis of models that incorporate heterogeneity.

[8] The history sequences determine beliefs, which determine decisions via a probabilistic choice function, which in turn, determines the evolution of the histories. The equilibrium is a set of probabilities associated with each finite history in a steady state. For an example of the calculations, see Capra et al. (2002).

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Appendix: Matlab Files (used for preliminary estimates based on UVA data only)

```
% The likelihood function will be maximized, with respect to the logit
% precision parameter (lambda) and the inequity aversion parameter (alpha)
% to be estimated. In particular, the negative of the log likelihood will
% be minimized by copying the following minimization search command to the
% Matlab command line and removing the comment symbol:

% [beta, fval, flags, output, gradient, hessian] = fminunc(@likelihood, [.1; .2], [])

% The [.1;.2] is the suggested starting values for lamda and alpha,
% respectively, and the [ ] indicates that no special options have been
% selected. At each iteration of the search, it calls a function,
% @likelihood, which calculates the (negative) log likelihood as a
% function of lambda and alpha.

% Once the program has run and produced estimates of lambda and alpha,
% copying the following command into the Matlab command line (without the
% comment symbol) will give standard errors of the estimates on the
% diagonals:

% sqrt(inv(hessian))
```

function logl = likelihood(beta)

```
lambda = beta(1);
alpha = beta(2);

% The data for the volunteer's dilemma game consist of the number of
% volunteer decisions and the number of no-volunteer decisions for each
% group size. Thus there will be a vector of group sizes(N), a vector of
% numbers of volunteers(n_vol), and a vector of numbers no-volunteer(n_no_vol)
% decisions. It is important the the order that group sizes are listed in
% N matches the order that is reported in n_vol and n_no_vol.

N = [2;3;6];
n_vol = [233; 192; 115];
n_no_vol = [207; 288; 365];

% Next enter the payoffs:

B = 1.00;   %payoff if at least one person volunteers
L = .20;    %payoff if nobody in the group volunteers
C = .20;    %cost of volunteering

% The nonlinear least squares routine finds the belief probability vector
% that minimizes the sum of squared deviations between belief and logit
% response probabilities. This sum is minimized at 0 in a QRE The [.1;.1;.1] vector in the command is a
        set of starting values for the QRE volunteer probabilities for group sizes 2, 3, and 6. This vector
        would have to be expanded to a 1x5 vector if the two additional group sizes are added.

qre_p = lsqnonlin(@belief_error, [.1;.1;.1], 0, 1, [], B, L, C, N, lambda, alpha);

for j=1:size(N)
   p(j)=qre_p(j);
```

```
end;

%  Thus p(1) is the probability of volunteering with the first group size
%  listed in N, p(2) is the probability of volunteering with the second
%  group size listed in N, etc., for the particular lambda and alpha values
%  in effect for a given iteration.  The log likelihood at the QRE for the
%  current value of lambda and alpha, is then calculated and replaced with
%  its negative, to be minimized:

logl=0;

for i=1:size(N)
   logl=logl + n_vol(i)*log(p(i)) + n_no_vol(i)*log(1-p(i));
end;

logl  =  -logl
```

function [belief_error_vector] = belief_error(p, B, L, C, N, lambda, alpha)

```
%  For a vector of belief probabilities, p, this function calculates logit
%  responses, and then belief errors, i.e. differences between belief and
%  response probabilities.

numN=size(N);

z=1;    % set z=1 or z=0 to estimate QRE with or without
        % inequity aversion, respectively

%  This loop calculates the belief error for each group size.  At the end,
%  we will have a belief error vector with each entry being the belief
%  error for the corresponding group size as it is listed in N.
for i=1:numN

   % Calculate expected payoffs:

   pay_vol(i) = B - C - z*alpha*(1-p(i))*C;
   pay_no_vol(i) = B*(1-(1-p(i))^(N(i)-1)) + L*(1-p(i))^(N(i)-1);

   % Logit quantal responses are ratios of exponential expressions:
   exp_pay_vol(i) = exp(lambda*pay_vol(i));
   exp_pay_no_vol(i) = exp(lambda*pay_no_vol(i));
   vol_response(i) = exp_pay_vol(i)/(exp_pay_vol(i) + exp_pay_no_vol(i));

   % The belief errors are differeneces between beliefs and logit
   % responses, which will be 0 in a QRE:
   belief_error_vector(i) = p(i) - vol_response(i);
end;


%  The function calculate_qre finds the quantal response equilibrium for
%  the volunteer's dilemma game specified below, as a function of the logit
%  precision (lambda) and the inequity aversion coefficient (alpha) that
%  you specify from the command line using the command:

%  calculate_qre(.1, .2);
```

```
% This command should be copied to the Matlab command line in the directory
% that contains the calculate_qre function.  Remember to uncomment the command
% and to replace the .1 and .2 arguments with the parameters you want to
% use, e.g. you could use the command:  calculate_qre(.1,0) to find the
% QRE with precision of .1 and no inequity averison.
```

function [p] = calculate_qre(lambda, alpha)

```
% Next specify the payoffs and group size treatments for the volunteer's
% dilemma game, e.g.:

B = 1.00;   %payoff if at least one person volunteers
L = .20;    %payoff if nobody in the group volunteers
C = .20;    %cost of volunteering
N = [2;3;6];

% The nonlinear least squares routine finds the belief probability vector that
% minimizes the sum of squared deviations between belief and logit response
% probabilities. This sum is minimized at 0 in a QRE.

qre_p = lsqnonlin(@belief_error, [.5;.5;.5], 0, 1, [], B, L, C, N, lambda, alpha);

for j=1:size(N)
   p(j)=qre_p(j);
end;
for i=1:size(N)
   pr_no_volunteers(i) = (1-p(i))^N(i);
end;
```