Crowd-Out in One-Shot Public Goods Games: Experimental Evidence on the Effects of Strategic Structure

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Abstract

We report on a laboratory experiment designed to test the robustness of crowd-out results in public goods games. We present subjects with a series of one-shot public goods games played without feedback. In all games, the equilibrium contribution level is positive, and neutrality results from the literature apply. We find that when subjects have an own-earnings-maximizing dominant strategy, we cannot reject the null hypothesis of full crowd-out, but when payoffs are specified using a Cobb-Douglas functional form in which the best response depends on the contribution levels of others, a government tax-and-spend policy on the public good increases efficiency. This result is driven by the removal by the tax-and-spend policy of the possibility of a form of free riding, in which players contribute below-equilibrium amounts in response to (incorrect) beliefs about the anticipated generosity of others.

1 Introduction

In an important theoretical paper, Andreoni [2] argued that government intervention in public goods provision might not enhance efficiency. He argued that individuals would respond to the intervention strategically by lowering their voluntary contributions, and therefore the government's action would "crowd out" private giving in equilibrium. A significant literature has tested the validity of this prediction using both field and laboratory data. A particular challenge in testing this theory in the laboratory is that the "pure altruist" model in the theory posits that agents receive positive utility from contributing to the public good. Many functional forms are consistent with the assumptions of the model, and as a result a variety of parameterizations have been chosen.

The full-crowd-out prediction is an equilibrium prediction. In essence, agents in the model are able to fully "undo" government policy by appropriately adjusting their private choices. The analysis therefore assumes that agents will contribute according to the equilibrium in the world without government intervention. Furthermore, if government intervention does occur, agents will believe that other agents will also recognize the neutrality of the equilibrium with respect to the policy, and adjust their behavior accordingly. As

Andreoni [2] points out, underlying neutrality results is the fact that the government policy can be undone via an arrangement of strategic changes which serve, effectively, as implicit transfers.

For some, and perhaps many, public goods settings, the conditions in which the assumption that agents have mutually accurate assessments about each others' contribution levels may not be present. Consider, for instance, contributions to disaster relief charities in the wake of major, unprecedented calamities such as the Indian Ocean tsunami of 2004 and Hurricane Katrina in the United States in 2005. In these situations, the need for contributions was dire and immediate, limiting the time in which individuals with pure altruist preferences could assess their optimal contributions given what others would contribute. Unlike public radio and television and annual telethons, the magnitude and nature of the disasters minimized the usefulness of prior experience in formulating assessments of others' actions and reactions.

In this paper, we report the results of an experiment designed to focus on these considerations. In our protocol, subjects participate in 16 public goods contribution games. The 16 games are played in sequence without feedback, to focus attention on the effects of initial beliefs on behavior. The public goods games are structured to maximize within-subject analysis on the effects of policy and framing. Four functional forms drawn from the literature are used to induce the basic social dilemma. Each of these functional forms is used in four games in a 2×2 design matrix. In one dimension, we consider the presence or absence of a government tax-and-spend policy. In the other dimension, we present the strategy space to the subject in two orientations, one in which higher choices correspond to more contributions to the public good, and one in which higher choics correspond to greater allocation to private consumption.

Theoretical models of public good crowd out address the change in voluntary contributions due to a government contribution financed by lump-sum taxes in a one-shot setting. Warr [14] is the first to explore public good crowd out. He suggests the market failure associated with public goods may not be corrected by a fiscal policy in which government revenues are collected from contributors and transferred to the public good. He finds that donors reduce their contribution by the amount of the tax collected, thereby completely crowding out the government contribution. Warr [15] further extends the analysis by demonstrating the private provision of a public good is unaffected by income transfers among contributors.

Bergstrom, Blume, and Varian [6], hereafter BBV, find that a government policy of equalizing income may reduce voluntary provision of the public good, as only the wealthiest individuals contribute. Whereas Warr [14] assumes only contributors are taxed, BBV assume contributors are a subset of the taxpayers. If non-contributors are taxed, then a government contribution may not be completely neutralized by reduced voluntary contributions, and crowd out will be incomplete.

Andreoni [2] assumes that utility is a function of private good consumption and the aggregate level of the public good (the "pure altruist" model). He finds the striking result that the supply of the public good is approximately invariant with respect to contributions from the government (complete crowd out), redistributions of income, subsidies to contributions, changes in the population, even an exogenous increase in contributions such as manna from heaven.

To test the null hypothesis of complete crowd out, laboratory experiments are designed so that equilibrium contributions are in the interior of the decision space before and after the tax. Laury and Holt[10] survey the literature on public good experiments with interior equilibria. Pertinent to the experiment in this paper, Laury and Holt compare contributions in dominant-strategy designs to non-dominant Nash equilibrium designs, and examine contribution patterns in designs that vary the location of the Nash equilibrium throughout the decision space. They find that average contributions lie between the Nash equilibrium and half of the endowment, and that contributions are less varied in the dominant-strategy designs.

Earnings in the standard public good contribution game are additively separable linear functions of private good consumption and the aggregate provision of the public good. A subject who maximizes her own earnings would contribute zero to the public good in this environment. Public good crowd-out games are either a series of public good contribution games if a within subject design is used, or use a different public good contribution game in each treatment with between-subject designs. As Andreoni [3] points out, in order to observe the response of voluntary contributions to a government tax and transfer policy, contributions need to be in the interior of the decision space both before and after the government policy. Payoff functions with interior Nash equilibria for subjects who maximize their own earnings have been used in public good crowd-out games to induce positive contributions. There are in general two methods to generate an interior solution in this class of games. One is the provision point setting, in which contributions to the public good is yields a low (perhaps zero) return unless total contributions reach a threshold (such as Marwell and Ames [12, 13]) and Bagnoli and McKee [5]). To date, there are no experimental tests of the complete crowd-out hypothesis in a provision point setting. An alternate method, and the focus of this paper, is to specify a nonlinear payoff function.

Experimental investigation of public good crowd out began with Andreoni [3]. The payoff model is an integer approximation of a Cobb-Douglas function of private good and public good consumption. The integer approximation was constructed to yield a unique and symmetric Nash equilibrium for own-money maximizing players. A between-subject design is employed in which half the participants played a treatment without a government tax and half played a treatment in which a portion of the token endowment is contributed to the public good. Groups of three played four rounds before the groups were randomly rematched. Incomplete crowd out was observed, which Andreoni suggests is consistent with a model of private benefits to the act of contributing (“warm glow giving”).

Chan et al. [7] employ a larger endowment, a within-subject design, and two tax treatments, but also assign participants to groups of three. The payoff model is additively separable in private good consumption, public good consumption, and the product of private good and public good consumption. This payoff model generates multiple Nash equilibria in two of the three treatments. Crowd out is found to increase with the amount of the tax. However, the Nash equilibrium contribution is no longer in the interior of the decision space in all treatments. The tax in one of the treatments is equal to the symmetric Nash equilibrium contribution in the no-tax treatment, so that any errors in contributions of an own-money maximizer are necessarily greater than the Nash prediction. Chan et al. find incomplete crowd out, and state this result is consistent with both warm glow giving and censoring of data due to the tax.

Gronberg et al. [8] utilize a payoff model that is quadratic in private good consumption which generates a dominant strategy. This design combined with a new graphical user interface are intended to make the own-money maximizing choice clear to participants. A dominant strategy greater than half of the endowment mitigates censoring of the data, and a new implementation of the tax no longer truncates the decision space

Authors	Andreoni (1993)	Chan et al (2002)	Gronberg et al (2009)	Luccasen (2009)
Payoff	Cobb-Douglas	Quadratic in public	Quadratic in private	Quadratic in public
Rematching	Every 4th round	Every round	Every round	Every round
Feedback	Yes	Yes	Yes	No
Within	Between	Within	Between	Within
Group	3	3	4	4
Endowment	7	20	100	10
Nash	3	5	80	4
Tax	2	3, 5	20	2
Mean	2.78, 3.35	5.31, 6.20, 6.69	84.5, 86.5	5.91, 5.98
Crowd-out	71%	70.4%, 75.5%	90%	96.5%

Table 1: Summary of experimental designs and results in laboratory studies of crowd-out.

in crowd out experiments. Groups of four participate in a between-subject design. Crowd out is again found to be incomplete, and group contributions are broadly consistent with the model of warm glow giving. However, analysis of individual contribution data reveals multiple player types.

Luccasen [11] correlates individual public good crowd out to behavior in the decomposed version of the ring game and personality traits identified by the Myers-Briggs Type Indicator test. The payoff model is quadratic in public good consumption, which generates a non-dominant Nash equilibrium. A within-subjects design is used in which participants make 10 choices in the "no tax" treatment then 10 choices in the "with tax" treatment. As opposed to previous crowd out experiments, feedback regarding choices of others was not given to participants. The estimated crowd out of 96.5% could not reject the null hypothesis of complete crowd out. The different experimental designs and results are summarized in Table 1.

Andreoni [4] notes that the rejection of the free-rider hypothesis in public good experiments contrasts with results in oligopoly and common resource experiments in which participants tend to reach Nash equilibria. One difference between these experiments is that a player's action creates positive externalities in a public good setting but negative externalities in oligopoly and common resource settings. Andreoni then compares public good provision in two equivalent settings. The first is a public good game in which each player's choice is a contribution to a public good which generates positive externalities to other players. The second is a common resource game in which each player's choice is private good consumption, which reduces the provision of the public good and generates negative externalities to other players. The incentives are identical in these two treatments and only the frame of the choice is different. The payoff model is linear which gives players a dominant strategy to consume only the private good in both treatments. In the public good setting, the mean contribution to the public good is 34% of the endowment; in the common resource setting the mean contribution to the public good is 16%. Despite identical incentives, the positive frame of the public good game generates much more cooperation than the negative frame of the common resource game.

The main result of this study is that, although average contributions are greater than the Nash equilibrium in 15 of the 16 treatments, crowd-out estimates are shown to range from 50% (statistically incomplete) to 90% (statistically complete) depending on the functional form of the payoff model. In the treatments with a dominant strategy, a subset of choices are at or near the dominant strategy equilibrium. The vast majority of deviations from this benchmark are in the direction that are efficiency improving. We interpret this as evidence that the graphical user interface clearly communicates the incentives of the game despite the absence of feedback, and that deviations from the dominant strategy were deliberate choices.

The paper is organized as follows. Section 2 summarizes the pure altruist model and basic neutrality result, and introduces the functional forms used to implement the model in the literature. Section 3 outlines the experimental design and protocol. Section 4 summarizes the results and presents formal statistical tests of our hypotheses. Section 5 concludes with a discussion of the implications of our findings.

2 Theory

The theoretical result in Andreoni [2] that a governmental tax-and-spend policy may not enhance efficiency in public goods games is based on the "pure altruist" model of public goods contribution. In this model, private individuals have a positive value for contributing to the public good; the "pure" in the name of the model refers to this value being independent of whether the contribution was an active choice by the agent. These neutrality results all share in common the feature that, in the absence of intervention, the equilibrium level of contribution is nonzero for at least some agents; therefore, the effects of the government policy are negated in equilibrium by the strategic response of the agents, who rearrange their contributions in reaction to the tax. Therefore, the government policy simply "crowds out" private contribution.

To fix notation, let there be n players, indexed by $i = 1, \ldots, n$. Each player i has some endowment $\omega_i > 0$, which he must allocate between two goods: a public good and private consumption. Let g_i be the amount player i allocates to the public good; therefore, the strategy space for player i is $g_i \in [0, \omega_i]$, where private consumption is then $\omega_i - g_i$. Let $G_{-i} = \sum_{j \neq i} g_j$ denote the sum of contributions by players other than player i. Player i has utility function of the form $u_i(g_i, G_{-i})$ depending only on his own contribution to the public good, and the sum of others' contributions to the public good.

To generate a setting in which the result of complete crowd-out applies, several choices for the functional form of u_i have been used. In the first laboratory study of the prediction, Andreoni [3] used a Cobb-Douglas form for the payoff function,

$$u_i(g_i, G_{-i}) = K(\omega - g_i)^{\alpha}(g_i + G_{-i})^{1-\alpha}.$$

Other studies have taken the approach of using a functional form which is quadratic in the amount of public good provided, such as the one in Anderson et al [1], which is of the form

$$u_i(g_i, G_{-i}) = K\left[(\omega - g_i) + m(g_i + G_{-i}) - \gamma(g_i + G_i)^2\right].$$

Each of these functional forms have the feature that the prediction used in the full-crowd-out result is a Nash equilibrium but not an equilibrium in dominant strategies. Therefore, the result does not take into account the possibility that beliefs about the contribution levels of others are not in equilibrium. To the extent that the public goods games in the field that we are modeling in theory and in the lab take place only once or infrequently, the equilibrium assumption of correct beliefs may be too strong. Our experimental design focuses on this problem specifically by presenting a series of public goods games without feedback on results.

However, if we admit both the possibility of "impure" motives for contribution which are not captured by the private payoff function u_i and that subjects will form inaccurate beliefs about the play of others, then no subject behavior is inconsistent with the assumptions. A control on the experimental design is provided by a payoff specification due to Keser [9], who shows that when payoffs are quadratic in the level of private consumption,

$$u_i(g_i, G_{-i}) = K\left[(\omega_i - g_i) - m(\omega_i - g_i)^2 + \gamma(g_i + G_{-i})\right],$$

then players have a dominant strategy.

3 Experimental design

We report on six experimental sessions. All sessions were conducted at the Economic Research Laboratory at Texas A&M University, using undergraduate students recruited through the laboratory's subject pool. Each session consisted of 12 participants, who played a sequence of 16 public goods games. Participants were randomly rematched in each game into groups of four. To approximate a one-shot decision environment while permitting within-subject comparisons of behavior, the 16 games were played without feedback on the results of previous rounds; subjects learned the outcome of all games at the end of the session. In each period, all subjects made their decisions before the next period began.[1] Most periods lasted between 2 and 3 minutes; the sessions as a whole, including instructions, the 16 games, and paying all subjects privately at the end, lasted 75 to 90 minutes.

Each game was calibrated so that Nash equilibrium play would result in earnings between $7.50 and $8.00. Subjects were paid the results of 2 of the 16 games. The games which were paid were determined by having two subjects each draw a numbered chip from the bowl at the conclusion of the session. Including the $5 show-up fee, Nash play would therefore lead to expected subject earnings around $20.00.

Four payoff specifications drawn from the literature were used:

1. A Cobb-Douglas payoff function, similar to the one used by Andreoni [3], mnemonically referred to as A:
$$u_i\left(g_i, G_{-i}\right) = 8 \times \frac{92}{122.61}\left(101 - g_i\right)^{\frac{61}{221}}\left(g_i + G_{-i}\right)^{\frac{160}{221}} + \varepsilon.$$
2. A quadratic payoff specification, similar to the one used by Chan et al [7], mnemonically referred to as C:
$$u_i\left(g_i, G_{-i}\right) = 8 \times \frac{96}{25920}\left[(200 - g_i) + (g_i + G_{-i}) + (200 - g_i)\left(g_i + G_{-i}\right)\right] + \varepsilon.$$

[1] We made this design choice consciously, since doing so necessarily limits the speed of the group to that of the most deliberate decision-maker in each period. Therefore, there is less incentive to make decisions quickly. This served as a partial control on the opportunity cost of subjects' time, since they could not easily influence the overall length of the session directly.

3. A quadratic payoff specification, similar to one in Anderson et al [1], mnemonically referred to as Q:

$$u_i(g_i, G_{-i}) = 8 \times \frac{19}{60}\left[(100-g_i) + 2(g_i + G_{-i}) - \frac{1}{320}(g_i + G_{-i})^2\right] + \varepsilon.$$

4. A quadratic payoff specification, similar to one in Keser [9]and Gronberg et al [8], mnemonically referred to as K:

$$u_i(g_i, G_{-i}) = 8 \times \frac{93}{77.5}\left[(100-g_i) - \frac{1}{160}(100-g_i)^2 + \frac{1}{4}(g_i + G_{-i})\right] + \varepsilon.$$

The parameters of these functions were chosen so that the Nash equilibrium contribution level for all is $g_i^\star = 40$. To make the results comparable across functional forms, we chose the base parameters so the equilibrium payoff was the same. Since it would then be possible to notice that certain strategy combinations always yielded the same payoff (and possibly interpret that as a focal point), for each game, a small ε was a small amount added so that the payoff at the Nash equilibrium of $g_i^\star = 40$ would not be exactly identical across games.

Each of these four functions was used in four games. The other two treatment dimensions involved whether or not a tax was imposed, and whether the choice made by subjects was how much of their endowment to keep, or how much to contribute. In two of the games with each function, a tax of $\tau = 25$ was imposed; this was a mandatory contribution to the public good. Following the practice in Luccasen et al, we maintained the decision space as $\{0, 1, \ldots, 99, 100\}$; therefore, the choice subjects made can be interpreted as choosing in percentage terms how to allocate their after-tax endowment between the public and private goods. Also, in two of the games with each function, the number chosen by the subject was the amount to contribute to the public good, and in two games, the choice was the amount to keep for the private good. Subjects saw each of the four combinations (no tax, choice of private; no tax, choice of public; with tax, choice of private; and with tax, choice of public) one time each.

Our design builds upon the methodology used in Gronberg et al [8] for presenting public goods games in a neutral frame while giving subjects a rich interface for exploring earnings possibilities. Subjects made a choice, labeled "your choice," from the set of integers $\{0, 1, \ldots, 99, 100\}$. The average choice of the other three participants in the group was called the "market statistic." In each game, subjects made their choice using a graphical interface (Figure 1) which illustrated visually the payoff surface they faced.

4 Results

Before addressing the results as they pertain to contribution levels and crowd-out, we first seek to validate our design against an external benchmark. With our use of a no-feedback design and an abstract framing and graphical interface, it is a concern that subjects may have been unable (or unwilling) to understand the financial and strategic incentives in the design of the experiment, and instead choose randomly, or based on other criteria. Our inclusion of specification K allows us to compare our results both against a strong theoretical benchmark - that own-earnings maximizers have a strictly dominant strategy - and against the

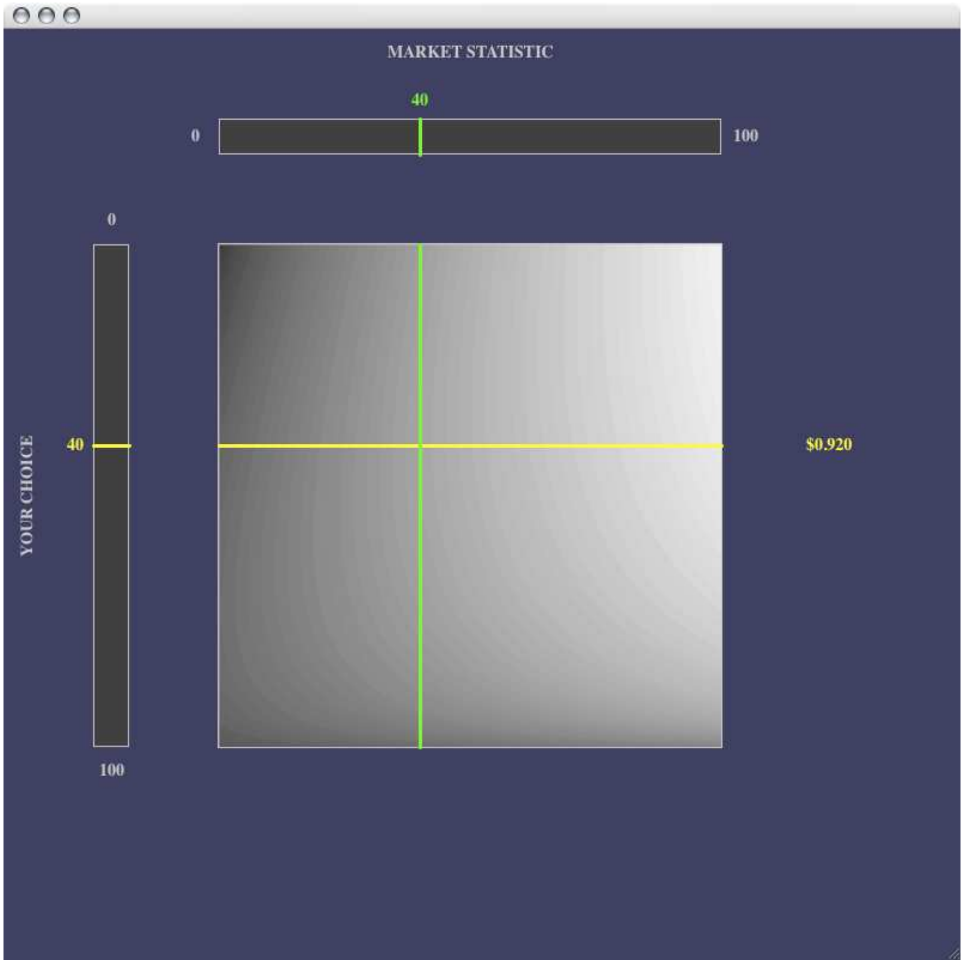

Figure 1: Screenshot of decision interface.

	n	**Dominant**	**Dominant $\pm$ 5**	**< Dominant**
Public, no tax	72	7	30	12
Public, with tax	72	19	27	8
Private, no tax	72	6	28	16
Private, with tax	72	16	25	8

Table 2: Summary of choices in specification K.

results in Gronberg et al [8]. In that paper, the same functional structure of payoffs was used, with the same style of graphical interface and terminology, but in a design in which subjects played the game for 10 periods with feedback on results after each period. The key qualitative findings there were that the dominant strategy was the modal choice, and that choices of strategies other than the dominant strategy were predominantly in the direction from the dominant strategy which moves the group towards the Pareto optimum.

Result 1. *The qualitative results of Gronberg et al [8] are replicated in specification K: choices cluster near the dominant strategy, and a majority of non-dominant choices are in excess of the dominant strategy.*

Support. Table 2 summarize subject choices in each of the four games using specification K. Overall, 38.1% of choices fall within 5 units in the strategy space. Overall, 84.8% of choices were in the direction in the strategy space which were efficiency-improving, relative to the own-earnings maximizing benchmark. These results are comparable to those reported in Gronberg et al. We conclude that the no-feedback design did not cause significant subject confusion in the games using K. Taken together with the Gronberg et al results, the results are consistent with the hypothesis that subjects are able to identify the direction of the Pareto-efficient outcome, even in the absence of framing clues other than the payoff surface.

In a no-feedback design, it would be wildly optimistic to expect that Nash equilibrium would be a useful point prediction of subject behavior, and, indeed, it is not. However, the presence of the dominant strategy in K does make a difference in the propensity of subjects to choose at or near the equilibrium contribution level.

Result 2. *Few subject choices overall match the Nash equilibrium prediction, either exactly or approximately. Subjects choose at or near the equilibrium significantly more often in K than in the other specifications.*

Support. Table 3 displays the percentage of choices which exactly match the Nash equilibrium in each treatment. The Nash equilibrium is played with low frequency in all treatments. This frequency is higher with function K, and highest with function K with a tax. The qualitative story remains the same if we relax our interpretation of the equilibrium, and consider choices within 5 of the equilibrium. Table 4 shows that frequencies of choices falling in this interval remain low in all treatments other than K.

Result 3. *Choices of boundary strategies are consistent with a simple model of naive best response.*

Function	Choose Public No Tax	Choose Public With Tax	Choose Private No Tax	Choose Private With Tax
A	1.4%	1.4%	0%	1.4%
C	2.8%	1.4%	1.4%	1.4%
Q	0%	2.8%	1.4%	0%
K	9.7%	26.4%	8.3%	22.2%

Table 3: Percentage of Nash equilibrium contributions by treatment ($n = 72$ in each cell)

Function	Choose Public No Tax	Choose Public With Tax	Choose Private No Tax	Choose Private With Tax
A	8.3%	6.9%	9.7%	11.1%
C	6.9%	5.6%	13.9%	4.2%
Q	4.2%	9.7%	11.1%	1.4%
K	41.7%	37.5%	38.9%	34.7%

Table 4: Percentage of Nash equilibrium contributions by treatment ($n = 72$ in each cell)

Support. Boundary strategies are potentially salient points within the strategy space. Table 5 summarizes the values of the market statistic for which the boundary strategies of contributing the entire after-tax endowment to the public good and contributing nothing from the after-tax endowment are best responses. Contributing nothing is a best response to a greater range of market statistics than contributing everything in each game, except for the dominant-strategy *K* environments. In each setting in which there is not a dominant strategy, the number of subjects choosing to contribute nothing exceeds those choosing to contribute their entire endowment. The result is reversed when in environments using function *K*, where zero contributions are rare.

These observations are qualitatively consistent with the hypothesis that a subset of subjects expect others will contribute, and contribute generously, which makes their earnings-maximizing choice to contribute nothing. As Result 4 will show below, these beliefs are not entirely unreasonable, since average contributions do exceed the Nash equilibrium in most of the treatments; in particular, in the with-tax treatments under *A*, *C*, and *Q*, it would be an own-earnings-maximizing response to choose to contribute nothing. This "strategic free-riding" hypothesis is strengthened by the absence of the effect when *K* is used, and low contribution levels can no longer be a best response.

We now turn our focus to the results on aggregate contributions and crowd-out. Table 6 summarizes subject choices for each of the 16 games. Unless otherwise noted, participant choices are converted to the tax-inclusive amount contributed to the public good. Inspection of the table suggests that, in most of the games, contributions are higher than the Nash equilibrium contribution, crowd-out is complete, and the framing of the choice does not significantly affect contributions to the public good. There are significant differences in contribution patterns and thus crowd-out by function. We now turn to the task of making these observations more precise using formal statistical tests.

Result 4. *Average contributions exceed the Nash prediction significantly in a majority of treatments.*

	Tax	Nash	Contribute All BR when	Contribute All Chosen	Contribute None BR when	Contribute None Chosen
A	No tax	40	$\emptyset$	2 (1.4%)	$[88, 100]$	30 (20.8%)
A	With tax	20	$\emptyset$	2 (1.4%)	$[44, 100]$	29 (20.1%)
C	No tax	40	0	19 (13.2%)	$[67, 100]$	25 (17.4%)
C	With tax	20	$\emptyset$	18 (12.5%)	$[33, 100]$	36 (25.0%)
Q	No tax	40	$[0, 20]$	7 (4.9%)	$[54, 100]$	24 (16.7%)
Q	With tax	20	$\emptyset$	4 (2.8%)	$[27, 100]$	38 (26.4%)
K	No tax	40	$\emptyset$	13 (9.0%)	$\emptyset$	0 (0.0%)
K	With tax	20	$\emptyset$	10 (6.9%)	$\emptyset$	3 (2.1%)

Table 5: Summary of basic strategic characteristics of games. Values expressed in the frame where subjects choose the percentage of their after-tax endowment to contribute to the public good.

Function	Choose Public No Tax	Choose Public With Tax	Choose Private No Tax	Choose Private With Tax
A	43.89 (3.10)	52.60 (2.29)	37.47 (3.40)	49.61 (2.12)
C	50.07 (4.14)	56.95 (3.17)	51.56 (4.13)	55.99 (3.24)
Q	46.15 (3.70)	56.01 (2.77)	49.21 (3.67)	47.09 (2.32)
K	55.89 (2.62)	58.03 (2.50)	57.79 (3.01)	55.61 (2.38)

Table 6: Average tax-inclusive contribution levels for all treatments; standard errors in parentheses.

Support. We begin our analysis by examining the predictive power of the Nash equilibrium contribution. Table 3 lists the frequency of the Nash equilibrium contribution of 40 for each treatment. Table 7 displays the results of a t-test of the null hypothesis that mean contributions are equal to 40 for each function by frame and tax condition. With a 95% confidence level, we fail to reject this hypothesis in only three of the sixteen cases.

Result 5. *Crowd-out is incomplete under functions A and C, and complete under K. The evidence for crowd-out under Q is mixed.*

Support. Our main economic question is whether the phenomenon of incomplete crowd-out is sensitive to the parametric design of the public goods game. To test this, we compute the within-subject difference of contributions in the with-tax condition minus the contributions in the no-tax condition for each functional

Function	Choose Public No Tax	Choose Public With Tax	Choose Private No Tax	Choose Private With Tax
A	0.213	0.000***	0.459	0.000***
C	0.018***	0.000***	0.007***	0.000***
Q	0.101	0.000***	0.014**	0.003***
K	0.000***	0.000***	0.000***	0.000***

Table 7: Summary of t-tests of hypothesis that the average contribution level is equal to the Nash level. (* = Significant at 10% level; ** = Significant at 5% level; *** = Significant at 1% level)

	Choose public		Choose private	
	Mean difference	**Wilcoxon p-value**	**Mean difference**	**Wilcoxon p-value**
A	+8.72	0.0007***	+12.14	$< 10^{-4}$***
C	+6.88	0.019**	+4.43	0.022**
Q	+9.86	0.001***	-2.11	0.780
K	+2.14	0.167	-2.18	0.214

Table 8: Crowd-out by function and by frame, measured by the mean difference in contributions in with tax minus no tax conditions. The null hypothesis is that both distributions are the same. p-values are for the Wilcoxon signed-rank test with null hypothesis of equality.

form and choice orientation, and perform the Wilcoxon signed-rank test for each of the eight cells. Table 8 reports the results. Crowd-out is incomplete at the 1% level when using function *A*, and at the 5% level when using function *C*. In both cases, contributions are significantly greater in the presence of a tax. We find no evidence that contributions are increased when using function *K*, in which there is an own-earnings-maximizing dominant strategy.

Further insight about this result can be gained by recalling the data in Result 3. In games with functions *A*, *C*, and *Q*, it is a best response against some conjectures about opponents' behavior to choose low contribution levels. Those contribution levels become impossible in the version of the game in which a tax is imposed, so the net contribution level of those subjects must necessarily be higher in the with-tax game. However, as we saw earlier, there is no such justification for choosing contributions less than the equilibrium under function *K*, and, indeed, such choices are rare; therefore, the introduction of the tax does not result in the elimination of many such "strategic free-riders."

Result 6. *The choice frame affects contribution levels mainly in frame A; when the choice frame affects contributions significantly, contributions are greater in the choose-public orientation.*

Support. Andreoni [4] reported that contribution behavior depended on the orientation of the choice frame; in a linear public goods setting, he reported that subjects were contributed more to the public good when the choice was framed as how much to contribute to the public good, rather than how much to keep for private consumption. While the language in our experimental design was neutral, we can investigate whether the orientation affects choice behavior. For each functional form and tax condition, we compute the difference in contribution for each subject between the choose-public orientation and the choose-private orientation, and test the null hypothesis of no effect against the two-sided alternative using the Wilcoxon matched-pairs signed-ranks test. Table 9 shows the mean differences and the p-value from the tests; positive differences reflect greater contribution in the choose-public orientation. We reject at the 5% the null of no difference in both tax conditions using function *A*, and also reject the null at the 1% level for function *Q* with a tax. In all three cases, contribution levels are higher in the choose-public orientation, which is consistent with Andreoni's result.

A second objective in including both decision orientations was as an extra test for validity. In each game, the equilibrium in the baseline no-tax, choose-public treatment was set at 40 in the decision space

	No tax		With tax	
	Mean difference	**Wilcoxon p-value**	**Mean difference**	**Wilcoxon p-value**
A	+6.42	0.011**	+2.99	0.017**
C	-1.49	0.728	+0.96	0.515
Q	-3.06	0.515	+8.92	0.007***
K	-1.90	0.333	+2.42	0.178

Table 9: Frame effect by function and tax treatment. Each difference is the mean difference between subject contributions in the public frame minus the private frame. p-values are for the Wilcoxon signed-rank test with null hypothesis of equality.

as seen by the subject. Therefore, in the no-tax, choose-private treatment, the equilibrium choice would be 60. With a tax, the equilibria are more extreme, with the decision space equilibrium being 20 in with-tax, choose-public, and 80 in with-tax, choose-private. Therefore, the small differences, measured in terms of overall implied contribution to the public goods, reported in the "with tax" column in Table 9 are imputed from subject choices which were far apart in the decision space. Therefore, we can conclude that subjects were processing at least the gross structure of the payoff surface, and that levels of contribution above the Nash equilibrium cannot be explained by a simple directional bias suggested by the interface design (e.g., a rule of thumb like "choose larger numbers because larger ones are better").

5 Conclusions

We utilize a within-subject design to focus on the effects of framing and tax policy on contribution levels and crowd-out. Our approach therefore complements much of the existing literature, which generally uses repeated play and across-subject designs. In practical terms, our experimental design offers us extra power in hypothesis testing through the use of matched pairs of observations within each subject. However, because doing this requires a no-feedback design, it comes at a cost that subjects will form heterogeneous expectations about the behavior of others, and therefore we observe significant heterogeneity in behavior. We therefore explore a region of the design space which may more accurately capture field environments where the mutual-consistency assumptions of equilibrium are unlikely to be valid.

To help distinguish between heterogeneous and inaccurate beliefs and simple confusion or indifference, we include games using function K to induce payoffs under which subjects had an own-earnings-maximizing dominant strategy. Since this functional form structure has been used in repeated-play designs with random rematching, the qualitative similarity of our results using K to previous findings helps establish some external validity. Our findings are consistent with the hypothesis that the lack of feedback was not confusing or discouraging to subjects, and that they were extracting information about the strategic structure and payoff consequences in each environment from the graphical interface.

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