Journal of Economic Psychology 58 (2017) 15–30

Contents lists available at ScienceDirect

Journal of Economic Psychology

journal homepage: www.elsevier.com/locate/joep

Belief heterogeneity and contributions decay among conditional cooperators in public goods games

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ARTICLE INFO

Article history:
Received 20 January 2016
Received in revised form 31 October 2016
Accepted 28 November 2016
Available online 29 November 2016

JEL Classification:
C71
C91

Keywords:
Experiments
Public goods
Voluntary contributions
Beliefs
Feedback

ABSTRACT

It is well-established that in finitely repeated linear public goods games, contributions decay over time with increasing free-riding. Prior researchers have appealed to notions of conditional cooperation coupled with self-interest to explain this phenomenon. We explore a complementary explanation for contributions falling over time. We show that there can be considerable heterogeneity in the distribution of initial beliefs among conditional cooperators, with subjects holding either optimistic or pessimistic beliefs regarding their peers' cooperativeness. Therefore, what is often perceived as purely self-regarding behavior may well be "conditional free-riding" by pessimistic reciprocators. These differences in prior beliefs, and subjects' contribution choices in response to those differing priors, can also generate a process of decay over and above self-serving biases or the interaction between reciprocators and free-riders.

1. Introduction

The experimental literature using voluntary contribution mechanisms to understand private provision of public goods is extensive.[1] In one-shot public goods games, average contributions range from 40% to 60% of endowments, with wide variations in individual contributions, ranging from 0% to 100%. If the game is repeated finitely, average contributions in the first round typically lie between 40% and 60%, but then decline as some participants start "*free-riding*," though the strong free-riding hypothesis of zero contributions is rarely borne out (Ledyard, 1995, chap. 2). Much research has been devoted to understanding the mechanisms behind such decay, which, in turn, can help in the design of institutions to promote pro-social behavior, particularly in "field" settings, as in Ostrom (1990), where the focus is on the management of natural resources.

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[1] Bohm (1972), Bohm (1983) and Marwell and Ames (1979, 1980, 1981) undertook some of the earliest experimental work in this area. In economics, notable early contributions include Andreoni (1988, 1990, 1995), Isaac and Walker (1988a), Isaac and Walker (1988b) and Isaac, McCue, and Plott (1985). Dawes, McTavish, and Shaklee (1977), Dawes (1980), Dawes, Orbell, Simmons, and van de Kragt (1986), Ostrom (1990), Ostrom, Gardner, and Walker (1994), Ostrom, Walker, and Gardner (1992) and Yamagishi (1986), Yamagishi (1988) are noteworthy early studies from other social sciences. Ledyard (1995, chap. 2) provides a comprehensive review.

http://dx.doi.org/10.1016/j.joep.2016.11.004
0167-4870/

Recent research has honed in on two possible explanations for declining contributions, both based on the idea of "*conditional cooperators*".[2] Players who are conditional cooperators make contributions that are positively correlated with their beliefs about the contributions of others (see Fischbacher, Gächter, & Fehr, 2001).[3] One strand of this literature, and indeed the broader literature on social dilemma games, assumes that any population is composed of at least two types of players: cooperators and free-riders. Cooperators start out making high contributions, but over time recognize the presence of free-riders, and reduce their contributions in retaliation, leading to the oft-seen pattern of decay.[4] Ambrus and Pathak (2011) provide a formal theoretical model along these lines.

The other strand of the literature is based on the idea of self-serving biases. Fischbacher and Gächter (2010), for example, report that a "*self-serving bias*" in conditional cooperation, where each agent attempts to contribute slightly less than the group average, leads to contribution decay.[5] Neugebauer, Perote, Schmidt, and Loos (2009) provide further evidence on self-serving biases. They examine subjects' own contributions and their beliefs about others' contributions when subjects get feedback about others' contributions and when they do not. Contributions decline only when feedback is provided. The authors report that overall contributions and beliefs are higher in the treatment without feedback, and that contributions are positively correlated with beliefs. Smith (2013, 2015b) extends this line of work by addressing the issue of beliefs being endogenous to contribution decisions. Using instrumental variables estimation, he estimates the causal effect of beliefs on contributions.

While readily conceding the validity of these models, we wish to explore a third channel for declining contributions over and above the two above-mentioned factors. We do this by drawing attention to the fact that even conditionally cooperative actors may possess heterogeneous prior beliefs about the potential cooperativeness of their peers. Consider an optimistic conditional cooperator who expects others to contribute 80% and a pessimistic conditional cooperator who expects others to contribute 20%. If each chooses a contribution level commensurate with these prior beliefs, then to the optimist, the pessimist will appear as a free-rider, even though the latter's free-riding is "conditional" on pessimistic prior beliefs.

In our experiment, prior to the start of play, we elicit beliefs from each subject about the average contributions of others in the first round. We find that there is considerable heterogeneity in beliefs and subsequent contributions are strongly related to these beliefs. We show that in the absence of any feedback about what others are doing, each type of conditional cooperator persists in contributing an amount commensurate with prior beliefs; optimists contribute a lot, while pessimists contribute little for extended periods.

However, when feedback is provided, so that subjects can see what others are contributing, the pessimists' low contributions instigate retaliation from optimists in the form of reduced contributions. Pessimists, once informed about the presence of more optimistic subjects, sometimes increase their contributions relative to those of others. But, in keeping with models of inequity aversion, any increases from pessimists are smaller in magnitude than reductions in contributions from optimists, resulting in the familiar pattern of decay. Here, the decay is caused by a mismatch in prior beliefs among conditionally cooperative players and exacerbates the decay due to the presence of free-riders or self-serving biases.[6]

We are certainly not disputing existing explanations, such as different preference types or self-serving biases, behind contributions decay. In fact, our experimental design cannot rule out the presence of free-riders or self-serving bias and indeed, we will find evidence in favor of both of these factors. But where this study adds value is to highlight that prior literature has treated conditional cooperators as a particular "type", but even within this group there may be considerable heterogeneity in terms of prior beliefs.[7] At times, what appears as free-riding may be conditional behavior by pessimistic reciprocators. This heterogeneity in prior beliefs can lead to similar dynamics in behavior and add to the process of decay. Even if the population did not contain free-riders, as long as there is sufficient heterogeneity in the prior beliefs of conditional cooperators one would expect to see a process of adjustment where the reduction in contributions from optimists are larger than any increases from pessimists, leading to contributions decay.

This, in turn, may imply different policy responses. If contributions decay is caused primarily by self-regarding behavior on the part of free-riders, then we might need to resort to either centralized or decentralized ("altruistic") punishments (Fehr

[2] Early writing in experimental economics identified a number of different factors that might cause this pattern of decay. These included kindness on the part of some and confusion on the part of others (Andreoni, 1995), the "warm glow" of giving (Andreoni, 1990), a combination of learning to play the dominant strategy and strategic play by self-interested players (Andreoni, 1988) and decision errors of various types (Anderson, Goeree, & Holt, 1998; Palfrey & Prisbrey, 1997).

[3] Other contributions to the literature on conditional cooperation include Sonnemans, Schram, and Offerman (1999), Keser and van Winden (2000), Brandts and Schram (2001), Kurzban and Houser (2005), Burlando and Guala (2005), and Chaudhuri and Paichayontvijit (2006), among others. Chaudhuri (2011) provides an overview.

[4] See Gunnthorsdottir, Houser, and McCabe (2007) for an example of this kind of argument. Smith (2015a) empirically examines the relationship between contribution heterogeneity and the path of average contributions, finding that contributions decline faster when there is more contribution heterogeneity, all else equal.

[5] Smith (2012) presents a re-examination of the Fischbacher and Gächter (2010) data, and reports that only partially matching one's own previous contributions is also a factor underlying contribution decay.

[6] Our work is closely related to Neugebauer et al. (2009), who also study the effect of feedback on the path of contributions. But we extend the Neugebauer et al. (2009) results by classifying subjects according to their prior beliefs and by examining the asymmetry in responses between optimists and pessimists. Chaudhuri, Graziano, and Maitra (2006) and Ashley, Ball, and Eckel (2010) examine asymmetric adjustment by high and low contributors from one round to the next and the process of convergence to the group average over time, but neither of the two studies attempts to connect those responses to prior beliefs.

[7] We wish to add a caveat about our use of the word "type". It is possible to think of conditional cooperators and free-riders as two different types of players. However, within the rank of conditional cooperators, it is also possible to think of those with optimistic or pessimistic beliefs about their peers as being different types (in terms of their differing prior beliefs). In what follows we will use the word "type" interchangeably but we believe that the actual meaning will be clear in the context in which the word is used.

& Gächter, 2000, 2002) to remedy this; on the other hand, if this free-riding is "conditional" and coming from pessimistic reciprocators then the policy prescription may well be different. There is now compelling evidence that *moral suasion* mechanisms, including communication, inter-generational advice or feelings of community, can successfully sustain cooperation even in the absence of costly punishments or assortative matching. See Chaudhuri (2011; particularly, Section 4.2 on sustaining cooperation via non-punitive mechanisms).

But if it is the presence of free-riders or self-serving biases that result in contributions decay, then it becomes difficult to explain how morally persuasive arguments about the preservation of virtuous norms of cooperation can succeed under those conditions. Indeed, the existing evidence (see for instance Chaudhuri et al., 2006 or Chaudhuri, 2011) suggests that communication devices enhance cooperation primarily via fostering more optimistic beliefs, which would be feasible if at least a plurality (even if not the majority) are conditional cooperators, some of whom have pessimistic beliefs to start with. If that is the case, then one would need a complementary argument couched in terms of heterogeneous beliefs, rather than heterogeneous types (in the form of cooperators and free-riders). This is what we attempt in this paper.[8]

We proceed as follows. Section 2 describes the experiment. Section 3 presents results and looks specifically at how belief heterogeneity can exacerbate contributions decay via asymmetric responses from pessimistic and optimistic subjects. Section 4 concludes.

2. Experimental design and procedures

2.1. Experimental design

The experiments were run in the Decide lab at the University of Auckland, using an internet-based public goods game designed specifically for this study. Subjects are undergraduate business and economics students, with no previous experience with the public goods game. Participants were seated in individual cubicles with dividers and instructed to refrain from communicating. At the beginning of each session, the instructions were read out loud (see Appendix A for a set of sample instructions) and questions were answered. We implement five treatments, which we explain below, after describing the common elements of all treatments.

We used groups of 4 in a "partners" protocol, keeping the composition of the groups unchanged for the duration of the experiment. This is because our primary research questions revolve around subjects' responses over time as they learn about their peers' actions. Changing the groups (as in a "strangers" protocol) would interfere with this process of learning about one's peers and responding to their actions.

In each round, each subject was endowed with 10 tokens and decided how to allocate the tokens between public and private accounts. Decisions occurred simultaneously among group members and subjects were restricted to making whole number allocations. Contributions to the public account were doubled and divided equally among the group's 4 members. In each round, the payoff of each subject *i* was:

$$\pi_i = 10 - c_i + 0.5 \cdot \sum_{j=1}^{4} c_j$$

where c_i is the contribution to the public account of subject *i*, in any group whose 4 members are indexed by *j*. The marginal per capita return (MPCR) from the public good was 0.5. The game was repeated for 24 rounds, and this was common knowledge at the start of play. At the end of each session, total earnings were converted into cash at the rate of NZ $0.05 per token, and added to a NZ $4 show-up fee. Sessions lasted about one hour.

Prior to starting the first round, we elicited subjects' beliefs about the other group members' contributions by asking them to fill out a questionnaire. We asked them to predict the average contribution to the public account from the other three members of their group in round 1. Subjects were paid according to the accuracy of their prediction using a quadratic scoring rule. The most they could earn for this prediction was NZ $1, while the minimum was zero. See Appendix A for details on the quadratic scoring rule.

We elicited beliefs to later classify subjects into one of three categories: (1) those who expect their group members to contribute 0, 1, 2, or 3 tokens ("*pessimists*"); (2) those who expect their group members to contribute 4, 5 or 6 tokens ("*realists*"), and (3) those who expect their group members to contribute 7, 8, 9 or 10 tokens ("*optimists*")[9]. Since subjects were restricted to making allocation decisions in whole numbers, the predictions could only take discrete values of 0, 1, . . ., 10 tokens.

A total of 256 subjects participated in the experiment: The average total payment (including a NZ$4 show-up fee) was NZ $18. The maximum amount earned was NZ$30.48 and the minimum was NZ$10.60.[10]

[8] In fact, Chaudhuri and Paichayontvijit (2006) extend Fischbacher et al. (2001) to show that when conditional cooperators become aware of the presence of other conditional cooperators in the group, there is an increase in contributions overall; and this increase is most pronounced for the conditional cooperators.

[9] We use 4–6 tokens as the benchmark because contributions are in whole numbers out of a 10 token endowment and prior studies have found that average contributions in round 1 start at around 40–60% of the endowment.

[10] At the time of the experiments in 2007–8, NZ$1 was worth approximately US$0.78.

2.2. Treatments

We implement five different treatments. Table 1 provides a summary. In the first treatment, subjects play the public goods game for 24 rounds, and receive feedback about total group contributions and their returns from the public good at the end of every round. This is the usual approach in public goods experiments and serves as our control treatment. We refer to this treatment as the **RbR** (round-by-round) treatment. There are 36 subjects (9 groups of four) in this treatment.

The second treatment is the No Feedback (**NF**) treatment, in which subjects play the public goods game for 24 rounds, but do not receive any information about the contributions of other group members, or their returns from the public account, until the end of the experiment. The only thing they know from round to round is how they allocated their endowments between the public and private accounts; they have no information about the choices made by others, or their earnings. This treatment has 64 subjects (16 groups).

The **NF** treatment serves two purposes. Suppose, that a contributing factor to contributions decay is that agents need time to learn the dominant strategy of free-riding. A process of *introspective learning*, where subjects play the stage game repetitively, even if they cannot observe the actions of their peers and there is no scope for social learning, should suffice for the subjects to learn the pecuniary benefits of free-riding.[11] If this type of learning is primarily responsible for contributions decay, contributions in the **NF** treatment should decrease over time. Otherwise, if subjects primarily best-respond to their prior beliefs and choose a contribution level commensurate with those beliefs, then in the absence of feedback about contributions, there will be minimal decay in contributions.

Comparing behavior between the **RbR** and **NF** treatments will allow us to observe whether there are asymmetric adjustments to feedback, with optimists reducing their contributions by a larger magnitude than pessimists increase theirs. It will also indicate the extent to which asymmetric adjustments to feedback underlie contributions decay.

In order to hone in on the role of information about peer contributions and focus on how subjects respond to this information we implement a third treatment – the Intermittent Feedback (**IF**) treatment. Here, subjects once again play for 24 rounds, but this time get feedback at the end of every fourth round. Throughout rounds 1–4, subjects are not told their group members' contributions or their earnings, and then at the end of round 4, each subject gets to see the aggregate (and average) contributions to the group account and his/her own returns from the public good for each of rounds 1–4. They receive similar feedback on rounds 5–8 at the end of round 8, rounds 9–12 at the end of round 12 and so on. Subjects therefore receive feedback 6 times in all; at the ends of rounds 4, 8, 12, 16, 20 and 24. The **IF** treatment has 60 subjects (15 groups).

Research in psychology suggests that a temporal patterning of trials (a string of decisions followed by an inter-trial interval when information about the previous string becomes available, followed by another string of decisions) leads to the information being processed differently from when it is provided on a continuous, round by round basis. See, for example, Kudadjie-Gyamfi and Rachlin (1996), McReynolds, Green, and Fisher (1983), and Rachlin (1995a, 1995b).[12]

The fourth treatment is similar to **RbR** in that subjects play for 24 rounds and get feedback at the end of each round. Except, here we elicit beliefs on multiple occasions; once before Round 1, as in the other treatments, but also before Rounds 5, 9, 13, 17 and 21, for a total of six belief elicitations during the session. We refer to this as the **RbR-MBE** treatment, where **MBE** refers to multiple belief elicitation. There are 60 subjects (15 groups).

The fifth and final treatment is similar to **IF** in that subjects play for 24 rounds and get feedback at the end of every fourth round. Except, here we also elicit beliefs on multiple occasions; once before Round 1 as in the other treatments, but also before Rounds 5, 9, 13, 17 and 21, for a total of six belief elicitations. This means that beliefs get elicited immediately after each feedback round. We refer to this as the **IF-MBE** treatment. There are 36 subjects (9 groups).

The **RbR-MBE** and **IF-MBE** treatments are parallel to the **RbR** and **IF** treatments in every manner other than the multiple belief elicitations. We conduct the **RbR-MBE** and **IF-MBE** treatments in order to determine how beliefs evolve over time, and in particular to determine if the relationship between beliefs and contributions changes over time. Specifically, we are looking for any "de-coupling" of beliefs and contributions, where the relationship between beliefs and contributions weakens toward the end of the sequence of rounds.

The reason that de-coupling is important is because it helps to shed light on whether there is some tendency for free riders to masquerade as conditional cooperators. Suppose, for example, that many free riders do masquerade as conditional cooperators in the early rounds of the game. Then in the early rounds, we should expect to see a close relationship between contributions and beliefs for these players. This relationship should weaken, or de-couple, as the free riders stop masquerad-

[11] Weber (2003) and Rick and Weber (2010) demonstrate that, across a variety of games, significant learning about equilibrium play occurs, even when subjects do not receive feedback about the actions of others with whom they are interacting. Neugebauer et al. (2009) refer to this as "*virtual equilibrium learning*".

[12] Evidence suggests that such patterning of decisions, where subjects are asked to commit to more than one decision at a time, tends to reduce impulsiveness and increase self-control. McReynolds et al. (1983) show, for instance, that dieters who plan their meals for the day in the morning (i.e. choose a string of meals) eat less than those who decide on a meal-by-meal basis. Frankl (2006) makes a similar argument, where he argues that if and when there is a temporal gap between stimulus and response, that space generates our power to choose our response. However, it is not straightforward to extrapolate the findings of this line of work to a social dilemma study such as ours because much of this work related to individual decision making tasks. In Kudadjie-Gyamfi and Rachlin (1996), for instance, the task is to maximize earnings over time. Subjects are faced with a choice between two equal monetary outcomes. One outcome is more immediate but the second, deferred payment option, results in less delay in future payoffs and leads to higher overall earnings. Their findings suggest that when choice-outcome pairs are were grouped in triplets, as opposed to being presented in single pairs, subjects chose the more immediate outcome less often and thereby maximized earnings.

Table 1
Summary of the five treatments.

Treatments	Number of rounds	Number of belief elicitations	Number of feedbacks	Number of subjects	Abbreviation
1. Round-by-round feedback	24	Once; before Round 1	24; at the end of each round	36	RbR
2. No feedback	24	Once; before Round 1	1; at the end of Round 24	64	NF
3. Intermittent feedback	24	Once; before Round 1	6; at the end of Rounds 4, 8, 12, 16, 20, 24	60	IF
4. Round-by-round feedback	24	6 times; before Rounds 1, 5, 9, 13, 17, 21	24; at the end of each round	60	RbR-MBE
5. Intermittent feedback	24	6 times; before Rounds 1, 5, 9, 13, 17, 21	6; at the end of Rounds 4, 8, 12, 16, 20 and 24	36	IF-MBE
			Total	256	

ing and instead begin making contributions consistent with their preferences as the rounds of the game proceed. A failure to observe such de-coupling would be consistent with the conjecture that there are few, if any, free riders masquerading as conditional cooperators in the early rounds of the game due to strategic considerations.

2.3. Hypotheses

On the basis of our discussion above, we formulate the following two hypotheses:

(1) *If we classify subjects based on their beliefs about others' contributions, then in the absence of feedback, each type will persist in contributing an amount that is commensurate with prior beliefs.*
(2) *Subjects respond to feedback about others' contributions by adjusting their contributions toward the group average; however, in keeping with models of inequity aversion, optimists will decrease their contributions by a larger magnitude than pessimists increase theirs, leading to contributions decay.*

Hypothesis 1 suggests that in the absence of feedback, those with optimistic beliefs will persist in contributing more than those with pessimistic beliefs. This hypothesis follows from prior findings about the behavior of conditional cooperators, including the results reported in Neugebauer et al. (2009).

Hypothesis 2 is derived from prior work looking at the dynamics of contributions and convergence to the group average over time (Ashley et al., 2010; Chaudhuri et al., 2006) as well as models of inequity aversion (Bolton & Ockenfels, 2000; Fehr & Schmidt, 1999), which suggests that players care both about their absolute and relative payoffs. Since payoffs in this game are a linear transformation of contributions, we can, therefore, assume that players respond to the ratio of their contributions to the average contribution of others. Inequity aversion models further suggest that people are more sensitive to envy than guilt. Optimists (pessimists) who contribute more (less) than the average will earn less (more) than the average, thereby suffering from (enjoying) disadvantageous (advantageous) inequity. Therefore, we expect optimists to decrease their contributions more than pessimists increase theirs, leading to contribution decay that is not dependent on either self-serving biases or the presence of free-riders. Since our approach is closely related to existing models of behavior, we eschew presenting a formal model.

3. Results

3.1. Support for Hypothesis 1

To provide support for Hypothesis 1, we rely on the data from the **NF** treatment. As noted above, we classify subjects into three types on the basis of their initial beliefs: (1) optimists, who believe that other group members would contribute an average of 7 tokens or more; (2) realists, who believe that their peers would contribute an average of between 4 and 6 tokens and (3) pessimists, who believe that group members would contribute an average of 3 tokens or less. The vast majority of our subjects (at least 50% or more in each treatment) are realists, possibly helping to explain why average contributions typically start in the range of 40–60% in a large number of previous studies (see Ledyard, 1995. chap. 2).[13]

In Fig. 1, we show the trends of contributions in the **NF** treatment by subject type (optimists, realists, and pessimists). Averaging over the 24 rounds, optimists contribute 6.4 tokens, realists 4.3 tokens and pessimists 1.7 tokens. For all three

[13] Gunnthorsdottir et al. (2007) use a similar classification to separate subjects into two types: "free-riders" who contribute 30% or less in the first round and "cooperators" who contribute more than 30%. Ones and Putterman (2007) report that early contributions are a reliable predictor of contributions in later periods. This finding is reinforced by Fischbacher, Gächter, and Quercia (2012), who demonstrate that people identified by the strategy method as conditional cooperators also behave as conditional cooperators under the direct response method. This suggests that early beliefs and behavior can serve as good predictors of behavior later in the game.

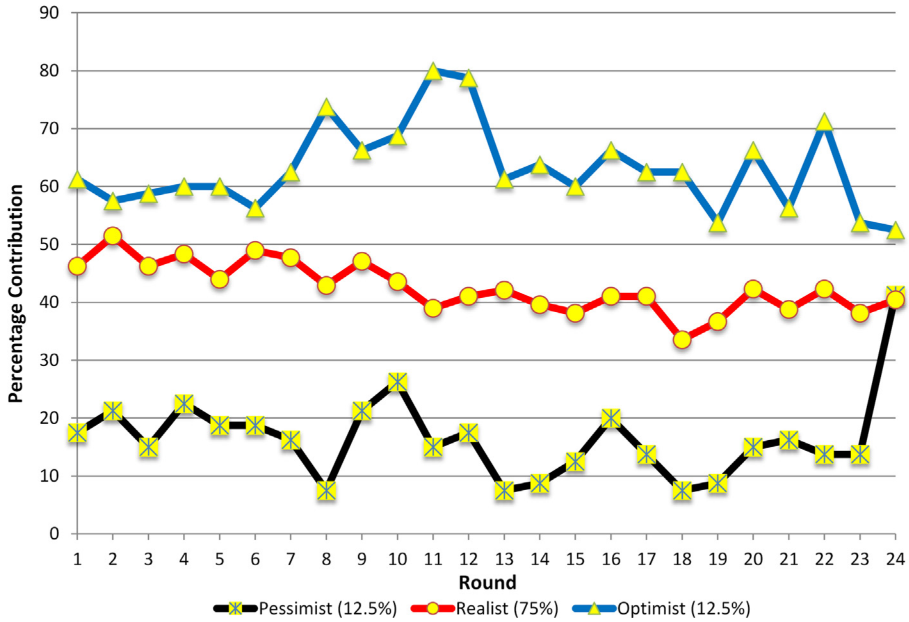

Fig. 1. Trends of contributions in the NF treatment (By Type).

subject types, there is very little contribution decay over the rounds. We attribute the sharp spike in the contributions of pessimists in the last round to an end-game effect, even though the spike is in the opposite direction of the game's Nash equilibrium. Rabin (1993) argues that in the presence of reciprocal motivations it is possible to think of the public goods game as a coordination problem with multiple equilibria involving both high and low contributions. Looking at Fig. 1, it appears as if each of the three different types are essentially trying to coordinate to three different equilibria involving high, medium, and low contributions.

There were nine subjects out of 64 (14%) in the NF treatment, that contributed nothing in all 24 rounds. As noted above, clearly there are free-riders in the group but they are a small minority. Incidentally, there were no subjects who contributed zero for all 24 rounds either in RbR or IF.

We next analyze the trends using regression analysis. We present the results of random effects regressions, but fixed effects and Tobit specifications (available from the authors upon request) provide very similar results. Our random effects results are slightly more conservative than the Tobit results in terms of the significance of the regressors.[14] For each subject type, individual contributions are regressed on a time trend (*round*). The results are presented in Table 2. An F-test of the null hypothesis that the three regression constants (which approximate the initial contributions of each type) are equal is highly significant ($\chi^2(2) = 82.28$; $p < 0.01$).[15] Furthermore, the three possible pair-wise comparisons between the three constants are all also highly significant (each with $\chi^2(1) \geqslant 6.95$; $p < 0.01$), providing strong evidence that initial contributions are commensurate with initial beliefs.

An F-test of the null hypothesis that the three *round* coefficients are equal is not significant ($\chi^2(2) = 2.64$; $p = 0.27$). This is in spite of the fact that for the *realists*, the downward trend in contributions is significant, whereas for the other types, the downward trends are not significant. Basically, the differences between the three *round* coefficients are not large enough (relative to the standard errors) for the F-test to be significant. In addition, none of the three pair-wise comparisons between the three *round* coefficients are significant at conventional levels. The results on the *round* coefficients indicate that there is no significant tendency toward convergence in contributions among the three subject types. Rather, the differences in contributions among subject types persist over time. The above evidence is strongly supportive of Hypothesis 1.

3.2. Support for Hypothesis 2

To provide support for Hypothesis 2, we turn to data from the **RbR** treatment, where subjects get feedback at the end of each round. In Fig. 2, we plot the trends of contributions by subject type. While all three types appear to follow a downward trend, any convergence is not immediately clear, except perhaps between the realists and the pessimists.

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[14] Tobit estimation imposes the assumption that the dependent variable has a censored normal distribution. While the censoring is clear, the normality is not as obvious. Least squares estimation does not involve this type of distributional assumption about the dependent variable.

[15] We use the seemingly unrelated estimation command (suest) in Stata. This is equivalent to running a pooled regression and estimating a round coefficient for each treatment using interaction effects. We favor our approach for ease of exposition because it removes the need to choose a reference group and interpret all the coefficients relative to the reference group.

Table 2
Regressions of contributions in the NF treatment (By Type).

Type	Optimists (1)	Realists (2)	Pessimists (3)
Round	−0.011	−0.047***	−0.003
	(0.035)	(0.013)	(0.032)
Constant	6.447***	4.837***	1.691***
	(1.227)	(0.248)	(0.418)
Subjects	8	48	8
Groups	7	16	6
Rounds	24	24	24
n	192	1152	192
R2	0.000	0.011	0.000

Notes: Standard errors adjusted for clustering at the group level are reported in parentheses
* Significance at 10%.
** Significance at 5%.
*** Significance at 1%.

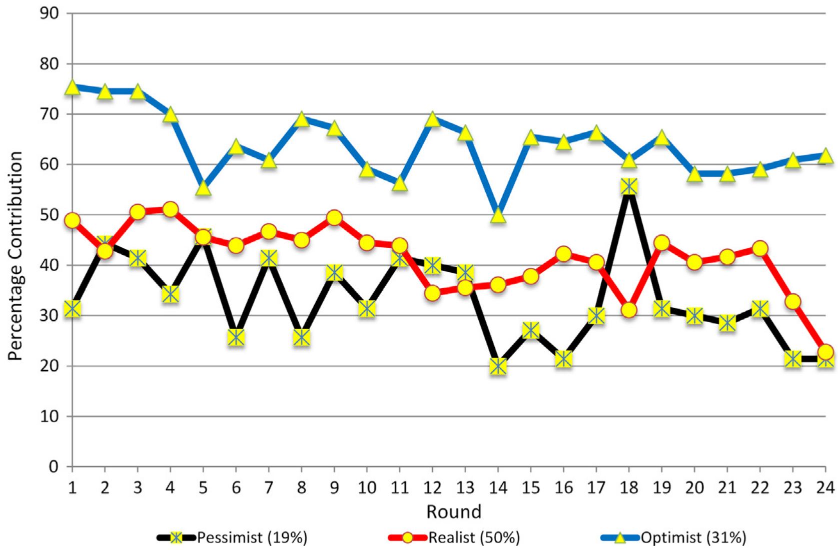

Fig. 2. Trends of contributions in the RbR treatment (By Type).

To examine this possibility further, we turn to regression analysis (see Table 3). An F-test of the null hypothesis that the three regression constants are equal is highly significant ($\chi^2(2) = 24.28$; $p < 0.01$). Furthermore, the optimist constant is significantly different from the realist constant (F-test $\chi^2(1) = 15.11$; $p < 0.01$) and from the pessimist constant (F-test $\chi^2(1) = 21.83$; $p < 0.01$). However, the difference between the realist and pessimist constants is only weakly significant ($\chi^2(1) = 3.18$; $p = 0.07$). In general, however, the starting points in terms of contributions for the three types are considerably different.

As for convergence, captured by the round coefficients, there is no significant evidence that the three types are moving toward one another as the rounds proceed (F-tests of the null hypotheses that the three round coefficients are equal, and of the three possible pair-wise comparisons between the three round coefficients are all insignificant; $\chi^2 \leqslant 0.31$; $p \geqslant 0.60$), providing no evidence in favor of convergence.

As noted above, when we discussed the different treatments, the psychological literature on patterning of choices (Frankl, 2006; McReynolds et al., 1983) suggests a plausible explanation for the lack of convergence in RbR. When subjects play for 24 rounds and get feedback on a continual basis, the feedback from any particular round is less salient. This results in limited convergence, with the optimists, in particular, hanging on to their optimism for an extended period. Consequently, we turn to the **IF** treatment to see if we can find support for Hypothesis 2; that is, to test if there is convergence to the average contribution over time, with optimists reducing, and pessimists increasing their contributions over time and whether the reduction in contributions from the optimists is larger in magnitude than any increase in contributions from the pessimists.

In Fig. 3, we show the evolution of contributions in the **NF**, **RbR**, and **IF** Treatments. Contributions clearly decline in the **IF** and **RbR** treatments (**IF**: 52% in round 1, 23% in round 24; **RbR**: 55% in round 1, 35% in round 24), but are relatively stable in the **NF** treatment (45% in round 1, 42% in round 24), providing our first suggestive evidence that contributions decline more when subjects receive feedback at discrete intervals.

Table 3
Regressions of contributions in the RbR treatment (By type).

Type	Optimists (1)	Realists (2)	Pessimists (3)
Round	−0.046	−0.065*	−0.051
	(0.037)	(0.032)	(0.044)
Constant	6.964***	4.960***	3.963***
	(0.644)	(0.566)	(1.016)
Subjects	11	18	7
Groups	6	9	5
Rounds	24	24	24
n	264	432	168
R2	0.009	0.021	0.015

Notes: Standard errors adjusted for clustering at the group level are reported in parentheses.
* Significance at 10%.
** Significance at 5%.
*** Significance at 1%.

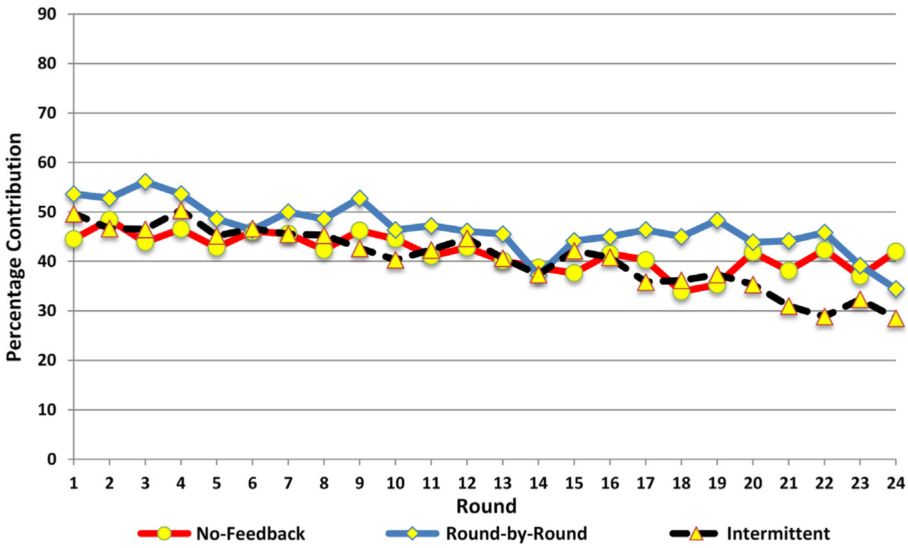

Fig. 3. Trends of contributions across treatments (NF, RbR, and IF).

Fig. 4 shows the pattern of contributions in the **IF** treatment by type: optimists, realists, and pessimists**.** We use vertical lines to indicate the rounds where feedback is provided to subjects. Compared to Fig. 3 above for the **RbR** treatment, the pattern of convergence in contributions for all three types – optimists, realists and pessimists – is clear here in the **IF** treatment.

In order to find support for Hypothesis 2, in Table 4, we analyze data from the **IF** treatment and initially focus on regressions (1–3), which estimate time trends for each of the three subject types. The statistical evidence of differences in initial contributions among the subject types is strong (F-tests of the null hypotheses that the three regression constants are equal, and of the three possible pair-wise comparisons between the three constants are all highly significant; $\chi^2 \geqslant 8.45$; $p < 0.01$).

As far as the *round* coefficients are concerned, the trend for optimists is negative and significant, for realists, it is negative and only weakly significant, and for pessimists, it is small, positive and not significant. An F-test of the equality of the three *round* coefficients is significant ($\chi^2(2) = 8.70$; $p = 0.01$), providing evidence that the trends are not the same for the different subject types. Making pair-wise comparisons among the three *round* coefficients, the difference in *round* coefficients between optimists and realists is not significant ($\chi^2(1) = 1.49$; $p = 0.22$), but the differences are significant between optimists and pessimists ($\chi^2(1) = 8.60$; $p < 0.01$) and between realists and pessimists ($\chi^2(1) = 5.32$; $p = 0.02$). The difference between optimists and pessimists indicates that optimists are decreasing their contributions faster than pessimists are increasing theirs, which supports Hypothesis 2 on the asymmetric adjustment of contributions.

In sum, the statistical evidence from regressions (1–3) provides evidence for convergence in contributions among subject types over time in line with Hypothesis 2. The convergence occurs as optimists and realists decrease their contributions, while pessimists keep their contributions pretty much unchanged in absolute terms.

In regressions (4–6), we hone in on the effect of receiving new information. That is, we examine the immediate effect of being given feedback about the average contributions of other group members. Recall that subjects were told at the ends of

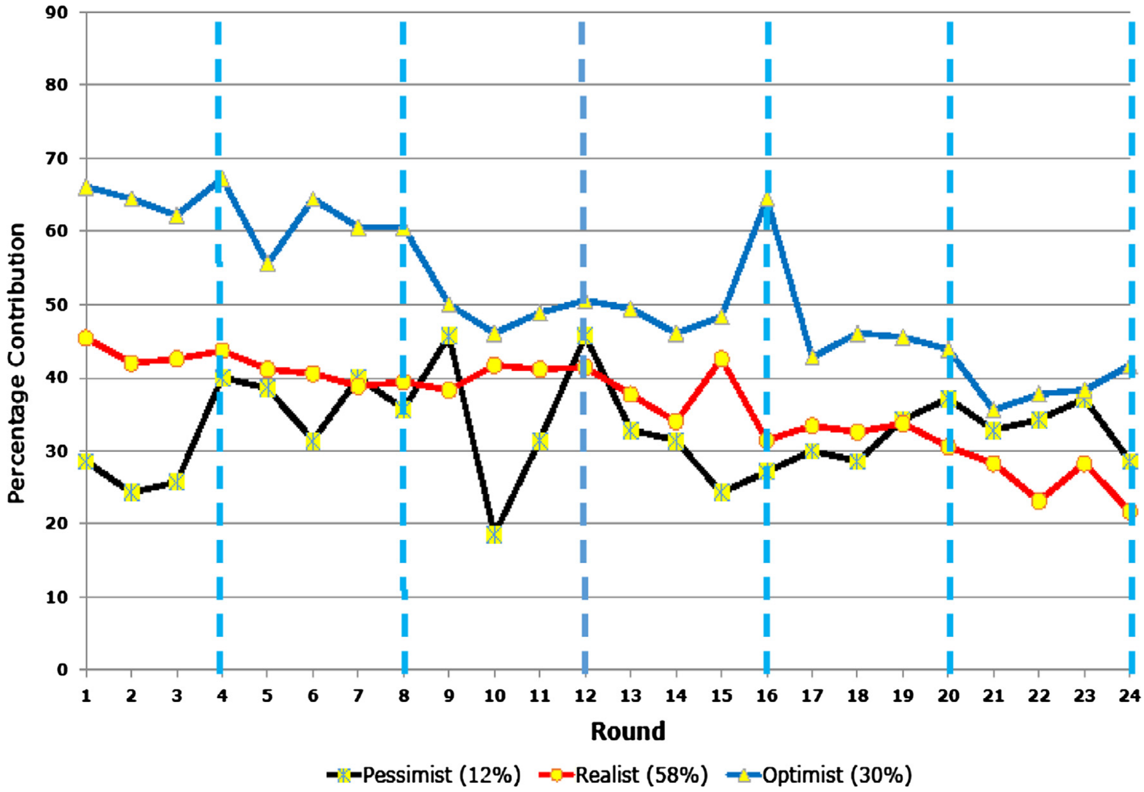

Fig. 4. Trends of contributions in the IF treatment (By Type).

Table 4
Regressions of contributions in the IF treatment (By Type).

Type	Optimists (1)	Realists (2)	Pessimists (3)	Optimists (4)	Realists (5)	Pessimists (6)
Round	−0.120**	−0.083*	0.002	−0.118**	−0.083*	0.001
	(0.048)	(0.044)	(0.062)	(0.048)	(0.044)	(0.062)
New info	–	–	–	−0.539*	−0.028	0.419
				(0.251)	(0.181)	(0.361)
Constant	6.647***	4.676***	3.248**	6.745***	4.681***	3.173**
	(0.643)	(0.526)	(1.027)	(0.615)	(0.520)	(1.075)
Subjects	18	35	7	18	35	7
Groups	12	15	7	12	15	7
Rounds	24	24	24	24	24	24
n	432	840	168	432	840	168
R2	0.049	0.028	0.000	0.053	0.028	0.004

Notes: Standard errors adjusted for clustering at the group level are reported in parentheses.
* Significance at 10%.
** Significance at 5%.
*** Significance at 1%.

rounds 4, 8, 12, 16, 20 and 24 the average contributions of their other group members in each of the four preceding rounds. We consider the subsequent rounds (rounds 5, 9, 13, 17 and 21) to be the "new information" rounds, or the rounds in which subjects have just received new information about their peers. The dummy variable *new info* thus takes on a value of 1 in a new information round and a value of 0 otherwise. The results from regressions (1–3) are all robust to adding the *new info* dummy variable.

Looking at these last three regressions a few things stand out. For optimists, the availability of information about others' contributions leads to a significant drop in contributions by approximately half (0.54) a token. There is no significant effect on the contributions of realists and the coefficient is close to zero. But the magnitude of the effect on pessimists is positive, as posited in our hypotheses. The coefficient is not statistically significant, which is possibly an artifact of the relatively small number of pessimists and consequently, the relatively large standard errors. But the results are economically significant, suggesting that with new information pessimists increase their contribution by about 0.42 token, which is certainly less than,

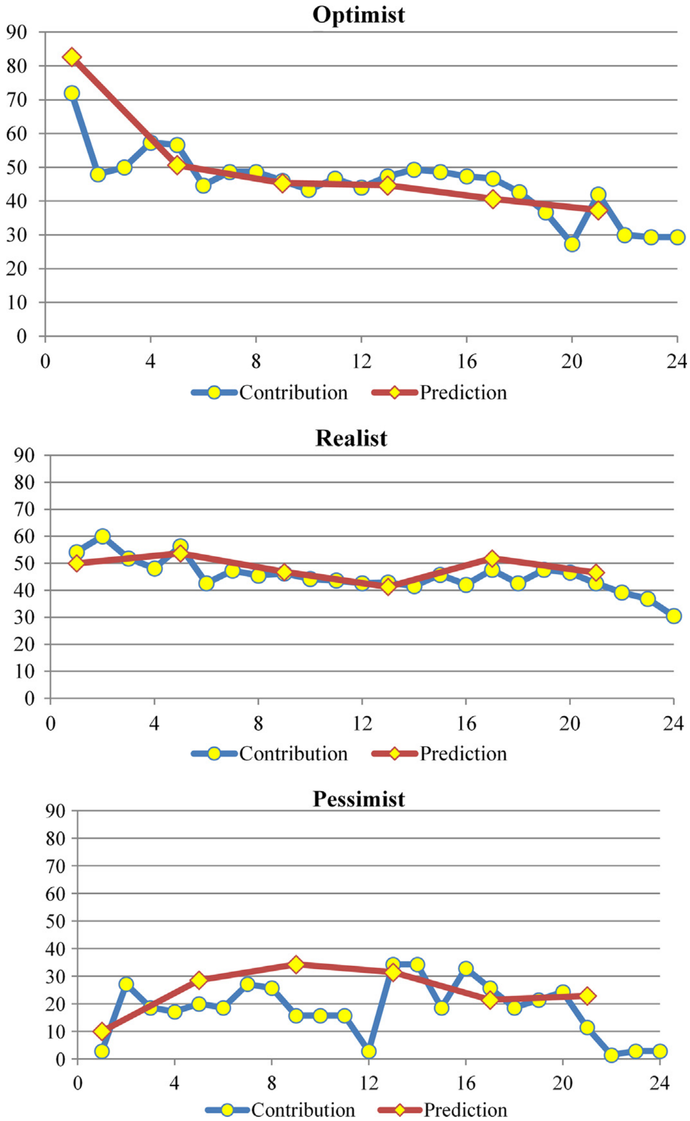

Fig. 5. Correlation between beliefs and contributions in the RbR-MBE treatment.

but comparable to the 0.54 token reduction coming from the optimists. Qualitatively, the estimates suggest that the effect of the new information (or feedback) is to promote convergence in contributions among types and that this convergence occurs in a manner consistent with Hypotheses 2.

However, we note that the evidence in favor of asymmetric convergence is not significant. Specifically, the decline in contributions from optimists (0.54) is not statistically different in magnitude from the increase coming from pessimists (0.42; $\chi^2(1) = 0.01$; $p = 0.94$). Thus, following information revelation, the signs of the coefficients (negative for optimists and positive for pessimists) and their magnitudes are consistent with Hypothesis 2 on asymmetric convergence, but the statistical evidence falls short of being significant.[16]

[16] We note, for the sake of completeness, that we ran two additional treatments as robustness checks. A potential question that arises in the context of the IF treatment, is whether it is the "*discreteness*" of the feedback that matters more or the "*number*" of feedbacks; namely, that subjects behave differently in the IF treatment because they pay more attention when there are fewer instances of feedback here, only 6 as opposed to 24 in the RbR treatment. In order to explore these, we ran the **RbR6** treatment. It is identical to **RbR**, except subjects play only six rounds and get information about average contributions and earnings at the end of each round. There are 60 subjects (15 groups) here. We conducted another treatment **"RbR6H"** where subjects play for 6 rounds and get feedback at the end of each round but have an endowment of 40 tokens in each of those 6 rounds. Given that subjects who play for 6 rounds potentially earn one-quarter of those who play for 24 rounds, the intention behind this treatment was to control for potential income effects by giving subjects four times the initial endowment than that in the RbR6 treatment. The evidence suggests that the discreteness of information in the IF treatment matters and leads to different patterns of responses from the different types. These results are not immediately relevant for our purposes and hence, on the advice of referees, we have omitted these results.

3.3. RbR-MBE and IF-MBE treatments

An anonymous referee on an earlier version of this paper asked how we can distinguish between two theories about the low contributors. They could be, as we have argued, conditional cooperators with pessimistic beliefs about the average contributions of others. They could also potentially be free riders, who either contribute nothing, or just enough so that their fellow group members do not reduce their contributions too much. This is a valid point. In order to respond to this, we present the results from the **RbR-MBE** and **IF-MBE** treatments. Our rationale is the following. Suppose that, contrary to our claim, pessimistic conditional cooperators are all free-riders, who were merely mimicking the others in order to lure them into making high contributions. The free-riders could then bail out from making contributions earlier and reap the benefits. What this suggests is that over time we would expect to see a bifurcation between the stated beliefs and actual contributions for pessimists. There are 15 optimists, 38 realists, and 7 pessimists in the **RbR-MBE** treatment and 6 optimists, 26 realists, and 4 pessimists in the **IF-MBE** treatment. The overall pattern of contributions in each treatment is roughly similar to the patterns of contributions in the absence of multiple belief elicitations and therefore we do not elaborate on this any further.

In Figs. 5 and 6 we present line graphs showing the evolution of beliefs and contributions for each type in the two treatments **RbR-MBE** and **IF-MBE**. It is clear that there is much stronger positive correlation between beliefs and contributions, both for optimists and for realists, than for pessimists. These figures do provide evidence of self-serving bias, with subjects' own contributions being less than their peers in several cases, but such bias seems much more pronounced for the pessimists than for the other two types.

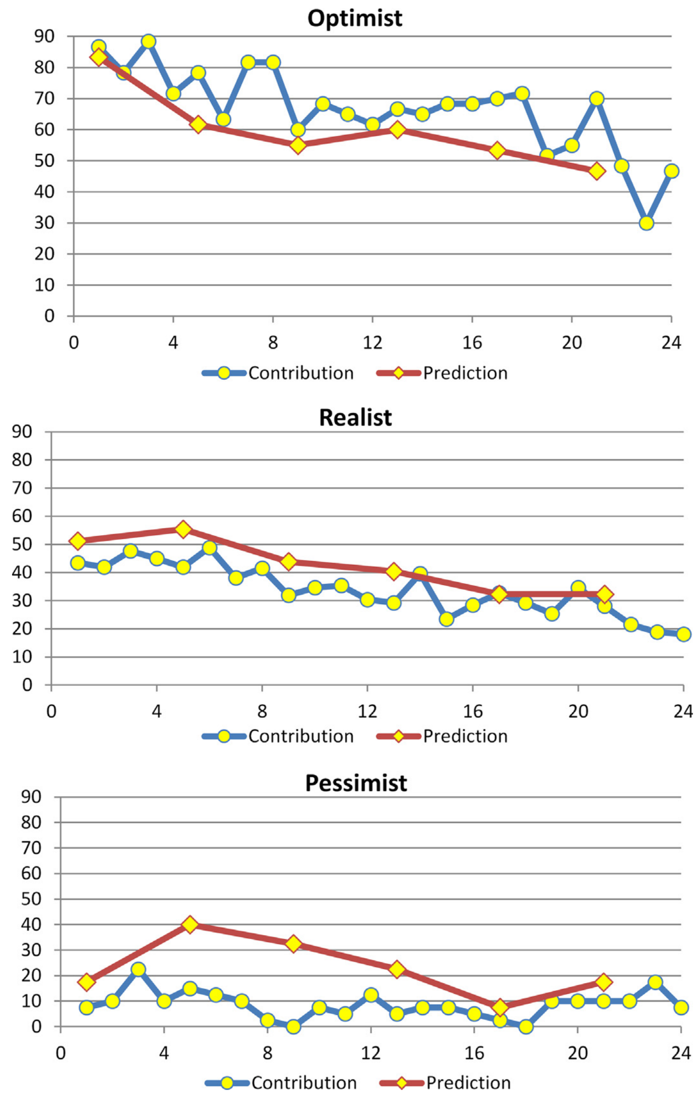

Fig. 6. Correlation between beliefs and contributions in the IF-MBE treatment.

To determine whether there is some separation between beliefs and contributions in the later rounds for pessimists, we carry out a series of non-parametric Wilcoxon signed rank tests, which analyze whether contributions are statistically different from beliefs. We do this separately for each type (optimists, realists, and pessimists) and in each round in which we elicited beliefs (i.e., rounds 1, 5, 9, 13, 17, and 21). We treat average beliefs and contributions at the group level as the independent units of observation. So specifically, for each subject type and group, in each belief elicitation round, we calculate the average contribution, and then compare it to the corresponding average belief. We report the results in Table 5.

By and large there are no significant differences between beliefs and contributions either in the **RbR-MBE** treatment or in the **IF-MBE** treatment for any of these comparisons. These findings suggest conditionally cooperative behavior both early on and in the later stages of the game. There is only one instance where there is a significant difference (at better than 5%) between beliefs and contributions, and the difference occurs for realists; in Round 13 ($z = 2.27$, $p = 0.02$). We therefore fail to find evidence that all pessimists are free riders "pretending" to be conditional cooperators in early rounds by contributing amounts commensurate with their beliefs, only to contribute less than their beliefs in later rounds. This implies that there must be at least some conditional cooperators in the sample classified as pessimists, and does not exclude the possibility that there are also some free riders in the sample.

The strong positive relationship between contributions and beliefs is confirmed by the regressions that we present in Table 6. We look at contributions in rounds with belief elicitation (1, 5, 9, 13, 17, and 21); independent variables include: (1) beliefs (in rounds 1, 5, 9, 13, 17, and 21), (2) the round, and (3) the interaction between beliefs and the round. We run a regression for each type (optimists, realists, and pessimists), while pooling the data from the RBR-MBE and IF-MBE treatments in order to increase statistical power. If there is "de-coupling" of beliefs from contributions as the rounds proceed, then we should expect the interaction term to be significant. In particular, it should be negative if in the late rounds, subjects start contributing less than what they believe others will contribute.

Beliefs have a large effect on the contributions of optimists and realists. However, for pessimists, the effect falls short of being significant at conventional levels. We speculate that this is at least partly due to the smaller number of observations for

Table 5
Wilcoxon signed rank tests of equality between beliefs and contributions.

Round		Optimists		Realists		Pessimists	
		RbR-MBE	IF-MBE	RbR-MBE	IF-MBE	RbR-MBE	IF-MBE
1	z-score	1.02	−0.93	−1.5	1.38	1.41	1.41
	p-value	0.31	0.35	0.13	0.17	0.16	0.16
5	z-score	−0.98	−1.29	0.31	**1.9**	1.08	1.63
	p-value	0.33	0.2	0.75	**0.06**	0.28	0.1
9	z-score	0.41	−0.37	0.34	1.6	**1.69**	1.39
	p-value	0.68	0.72	0.73	0.11	**0.09**	0.17
13	z-score	0.16	0.19	−0.03	**2.27**	0.21	1.39
	p-value	0.88	0.85	0.98	**0.02**	0.83	0.17
17	z-score	−0.21	−0.93	1.21	0.42	−0.32	1.39
	p-value	0.83	0.35	0.23	0.68	0.75	0.17
21	z-score	−0.11	**−1.83**	1.37	1.08	1.06	1.37
	p-value	0.92	**0.07**	0.17	0.28	0.29	0.17

Table 6
Regressions of contributions in the RBR-MBE and IF-MBE treatments.

Type	Optimists (1)	Realists (2)	Pessimists (3)
Belief	0.788***	0.557***	0.212
	(0.102)	(0.216)	(0.147)
Round	0.025	−0.026	−0.003
	(0.053)	(0.064)	(0.026)
Belief x rd	−0.000	−0.002	0.020
	(0.007)	(0.013)	(0.015)
Constant	1.312	2.100*	0.421
	(1.093)	(1.149)	(0.215)
Subjects	21	64	11
Groups	14	24	9
Rounds	6	6	6
n	126	384	66
R2	0.455	0.202	0.128

Notes: Standard errors adjusted for clustering at the group level are reported in parentheses.
* Significance at 10%.
** Significance at 5%.
*** Significance at 1%.

pessimists. More importantly though, the interaction term is not significant for any of the subject types, failing to provide any evidence consistent with de-coupling.

4. Concluding remarks

We present evidence that the oft-seen pattern of contributions decay in linear public goods games can be explained using heterogeneity of initial beliefs about the contributions of others. In doing so, we complement extant theories that assume interactions between cooperators and free-riders or the existence of self-serving biases. We show how contributions decay may be related to social learning, or the process by which subjects start the game with certain beliefs, observe how much others are contributing, and choose future contributions such that there is a tendency toward converging to the group average.

A majority of our subjects are conditional cooperators who match the anticipated contributions of others. Those with optimistic beliefs start out with high contributions. Realists, who have reasonably accurate beliefs, contribute moderate amounts, and pessimists, who expect others to contribute low amounts, contribute low amounts themselves. Pessimists tend to maintain their absolute contribution levels over time, and increase their contributions relative to the realists who primarily determine the group average. The asymmetry in responses from those with differing prior beliefs appears to be a cause of the decay in contributions.

The issue of whether decaying contributions are caused by interaction between cooperators and free-riders or by interaction among conditional cooperators with different initial beliefs has implications for the design of mechanisms that can sustain cooperation over time. While we do not claim to have resolved the issue, we present informative, suggestive evidence consistent with the latter explanation. The former calls for punitive measures such as costly punishments, social ostracism or shaming to keep free riding in check. But if contributions decay is due to heterogeneity in initial beliefs, more benign measures such as communication, exhortative advice or expressions of disapproval, assortative matching, or feelings of community that generate appropriately optimistic beliefs might be sufficient. The appropriate policy implications therefore remain an important topic worthy of further research.

Acknowledgements

We thank the University of Auckland for funding this work. We are grateful to Geoff Brooke and Miwah Van for research assistance. We thank James Andreoni, Catherine Eckel, John Hillas, Tibor Neugebauer, Louis Putterman, Alan Rogers, Erwann Sbai, Jason Shachat, two anonymous referees for this journal, seminar participants at the Centre for Studies in Social Sciences (Kolkata), Monash University, University of Canterbury, University of New South Wales, University of Otago, Victoria University of Wellington and participants at various conferences including the Sixth Biennial Social Dilemma Conference at Brown University in May 2015 and a number of Economic Science Association Meetings for valuable feedback. All errors are the responsibility of the authors.

Appendix A

A.1. Instructions for the NF, IF and RbR treatments

This is an experiment in economic decision-making. The University of XXX has provided the funds to conduct this research. The instructions are simple. If you follow them closely and make appropriate decisions, you may make an appreciable amount of money. This money will be paid to you in cash at the end of the experiment.

You are in a market with 3 other people, i.e. you will be part of a 4 person group. The composition of the group you are in will remain unchanged during the entire session. You will not learn the identity of the other people in your group at any point.

The experiment will consist of a number of rounds. At the beginning of each round each participant will have an endowment of 10 tokens. In each round, each participant will choose – in whole numbers - how many tokens (ranging from 0 to 10) to allocate to a private account and how many tokens (ranging from 0 to 10) to allocate to a public account. For each round, these two numbers should add to 10, the total number of tokens you have for that round. The total number of tokens allocated to the public account will be **doubled** and divided equally among all 4 participants. Your personal earnings for this round will equal the number of tokens you allocated to your private account plus the number of tokens you get back from the public account (the latter may be a fractional amount).

Each new round will proceed in the same way. Tokens allocated to the private account in any round do not carry over to the next round. Every round you start with a fresh endowment of 10 tokens.

The next paragraph differs in the three treatments.

A.2. In the round-by-round feedback treatment the next paragraph states

This experiment will last for 24 rounds. In each round you will decide how to divide your 10 tokens between the private and public accounts. At the end of each round you will get to see the total tokens contributed to the public account (but not the contribution made by individual members of the group) and your own earnings for the round.

A.3. In the intermittent feedback treatment the next paragraph states

This experiment will last for 24 rounds. In each round you will decide how to divide your 10 tokens between the private and public accounts. You will get to see the total tokens contributed to the public account (but not the contribution made by individual members of the group) and your own earnings every four rounds. That is you will make decisions for Rounds 1 through 4 without learning what the total contribution to the public account is or what your earnings are. Then you will get to see this information for all the four rounds at the end of Round 4. Then you will make decisions for Rounds 5 through 8 without learning what the total contribution to the public account is or what your earnings are. Then you will get to see this information for all the four rounds at the end of Round 8. Then you will make decisions for Rounds 9 through 12 without learning what the total contribution to the public account is or what your earnings are. Then you will get to see this information for all the four rounds at the end of Round 12 and so on till Round 24.

A.4. In the no feedback treatment the next paragraph states

This experiment will last for 24 rounds. In each round you will decide how to divide your 10 tokens between the private and public accounts. However you will not get to see any information about the tokens contributed by others to the public account or your earnings per round till the very end of the session. That is you will only learn about the total contributions to the public account and your earnings after all 24 rounds are over.

The rest of the instructions are the same in all three treatments.

At the end of the experiment your total earnings from the 24 decision rounds will be added up and converted into cash at the rate of 5 cents per token.

Once you log into the computer you will be assigned a subject ID. Please make a note of this and write down this number on the top of each page of your instructions.

Are there any questions?

Please answer the following question before the first round begins.

What is the average contribution to the public account that you expect from the other three members of your group ***in round 1***? Do not include yourself and round to the nearest integer. Please choose one:

____ 0	____ 3	____ 6	____ 9
____ 1	____ 4	____ 7	____ 10
____ 2	____ 5	____ 8	

You will be paid for this prediction in the following way. Your earnings will be $1.00 minus the square of the difference of your prediction and the actual average choice.

Suppose you predict that the average choice of the other three group members in Round 1 will be 8. Suppose the actual average turns out to be 4. In this case the absolute difference between the two numbers is 4. The square of this difference is 16. Then you will earn $1.00–0.16 = $0.84. On the other hand, suppose you predict that the average choice of the other three group members in Round 1 will be 3. Suppose the actual average turns out to be 9. In this case the absolute difference between the two numbers is 6. The square of this difference is 36. Then you will earn $1.00–0.36 = $0.64.

PREDICTION BEFORE ROUND 1

Predicted Average	**Actual Average**	**Difference**	**Square of Difference**	**Earnings ($1 – Square of Difference)**

RECORD SHEET

Show-up Fee:	**$4.00**
Earnings from Prediction:	__________
Earnings from Experiment:	__________
TOTAL	__________

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