1. Introduction

Humans see other humans as members of groups, and they treat them differently based on their group membership. Cognitively, they classify humans as members of different groups, form stereotypes about other groups, and track group reputations. Motivationally, they form positive or negative attitudes to other groups and may discriminate against some groups. They may also reciprocate towards groups as a whole: that is, they may respond to one person's actions by acting differently towards his or her fellow group members. We have experimental evidence for group reciprocity, but so far there is no theoretical account of how it might have evolved. This paper sets out an evolutionary model of group reciprocity. The requirements are quite minimal. Individuals know other individuals' group membership, and they can recall outgroup members' past behaviour towards them. That is enough for group reciprocity to evolve in a finitely repeated prisoner's dilemma. So, intergroup cognition alone is enough to make intergroup reciprocity evolutionarily stable.

Group reciprocity is important in several ways. Theoretically, interethnic peace may be sustained by the threat of reciprocation. This could have allowed humans to live in peace with neighbouring groups (perhaps punctuated by episodes of punitive conflict), whereas chimpanzees always attack neighbouring bands on contact (Wrangham and Glowacki, 2012). Group reciprocity could also enable deeper forms of intergroup cooperation, such as trade. So, the capacity for group reciprocity may be a stepping stone in the evolution of human cooperation at scale. Because group reciprocity entails that individuals keep mental records of groups' past behaviour, it may also provide an evolutionary basis for the phemonenon that humans hold attitudes towards entire groups (Brewer and Kramer, 1985; Neuberg and Schaller, 2008).

Group reciprocity is also related to generalized upstream reciprocity or "paying it forward" (Boyd and Richerson, 1989; Nowak and Roch, 2007). The literature has concluded that it is hard for generalized upstream reciprocity to evolve except in special circumstances. In our model, a bounded form of generalized upstream reciprocity can evolve, because reciprocal cooperation between groups provides an evolutionary advantage to those groups. Without groups, generalized upstream reciprocity does not allow for this kind of group selection argument. Possibly, observed cases of generalized upstream reciprocity (e.g. Mujcic and Leibbrandt, 2018; Yuan et al., 2019) may involve elements of group reciprocity.

Practically, understanding the evolutionary basis for intergroup categorization could help us to understand how it plays out in modern settings. That includes the prejudice and stereotyping mentioned above, and also violent conflicts, including ethnic violence and civil war, where intergroup reciprocity may be involved (Haushofer, Biletzki, and Kanwisher, 2010; Horowitz, 1985, 2001).

Here is the logic behind our result. Groups of group-reciprocators establish cooperative relationships with other groups of group-reciprocators, while they defect against groups of selfish types. So, when some people are group reciprocators, individual fitness depends on one's group's reputation. Group reciprocators contribute to this reputation, which is a group-level public good. Thus being a group reciprocator is good for the group but costly for the individual. This then gives rise to a standard intrademic group selection model, where the group-level advantages balance out the individual-level costs (Wade, 1978; Wilson, 1983). Selfish free-riders within a group of mostly group-reciprocators get the highest payoff, but this is balanced out because most selfish types are in mostly-selfish groups, who have too few reciprocators to sustain intergroup cooperation.

We use computations to check the robustness of our theoretical model. Our results confirm that even in small populations, or with relatively rare interactions, group reciprocity can evolve.

Our model also suggests some insights about how group reciprocal motivations are shaped by evolutionary pressure. The most robust forms of group reciprocity have high thresholds of cooperation - that is, reciprocators only cooperate with groups a high proportion of whose members previously cooperated towards them. These high thresholds make it less likely that selfish free riders will invade, since only groups which are almost all reciprocators get the benefit of mutual cooperation. The resulting equilibrium is ”trigger happy”: it sustains a high level of cooperation, but is also sensitive to small amounts of defection.

2. Literature review

Several experiments show evidence for group reciprocity, also known as "vicarious revenge" (Gaertner, Iuzzini, and O'Mara, 2008; Hugh-Jones and Leroch, 2017; Hugh-Jones, Ron, and Zultan, 2019; Lickel et al., 2006; Romano, Saral, and Wu, 2022; Stenstrom et al., 2008). There is also field evidence of reciprocity in violent intergroup conflict (Haushofer, Biletzki, and Kanwisher, 2010). Anthropologists have recorded feud institutions, where group reciprocity is a normative expectation and where there may be collective mechanisms for managing and adjudicating feuds (Boehm, 1984; Chagnon, 1988).

What we lack is a theory of how group reciprocity might evolve. While there are evolutionary theories to explain individual reciprocity and revenge (McCullough, Kurzban, and Tabak, 2013a), there is none for group reciprocity. This is a problem, because one can't simply assume that the same forces are behind the evolution of individual reciprocity and group reciprocity (McCullough, Kurzban, and Tabak, 2013b; Pietraszewski, 2013). In particular, group reciprocity is a form of "upstream reciprocity", where an individual who is helped or harmed by someone becomes more likely to respectively help or harm other third parties (Boyd and Richerson, 1989). It is thought hard for upstream reciprocity to evolve, because it does not target reciprocity in a way that might lead to stable bilateral relationships (Nowak and Roch, 2007).[1] Indeed, there is only mixed experimental evidence for upstream reciprocity, with several papers finding it absent or transient (Ben-Ner et al., 2004; Greiner and Levati, 2005; Horita et al., 2016; Stanca, 2009; van Apeldoorn and Schram, 2016).

We show that the existence of groups makes this problem easier, by allowing different *groups* to form bilateral relationships. Group reciprocity allows

[1] By contrast, we have satisfying theoretical explanations for why group membership might matter for "downstream" or "indirect" reciprocity, where people help someone who previously helped others. In particular, group membership may act as a "container" for this kind of reciprocity, because fellow group members expect to interact often in future, or because coalitions are valuable resources worth defending by third-party punishment (Delton and Krasnow, 2017; Romano, Saral, and Wu, 2022; Yamagishi and Kiyonari, 2000).

groups to enter mutually beneficial cooperative relationships, achieving a fitness advantage. This group selection logic does not apply when reciprocity is targeted at the whole population.

Columbus et al. (2023) argue informally that group reciprocity can be supported by reputation mechanisms at group and individual level. Groups have an interest in appearing ”tough”, i.e. able to reciprocate harms; individuals who reciprocate on behalf of their group may gain an individual reputation for toughness and (parochial) prosociality. We agree that these mechanisms can enhance group reciprocity, but we note that they aren't necessary. As we show below, group reciprocity evolves even when groups don't possess any power of collective action (for instance, they can't collectively decide to sanction outgroups, or force their members to behave a certain way). Simply making individuals' group membership visible is enough to let group reciprocity evolve. We also don't require group membership to be heritable: in the model, groups are reformed at random after every generation. This is a strength of the theory because evidence shows that humans can quickly perceive and form coalitions even among strangers (Kurzban, Tooby, and Cosmides, 2001; Tajfel et al., 1971; Tooby and Cosmides, 2010).

The logic of group reciprocity does not only explain group reciprocal motivations. An essential part of any group reciprocal model is that individuals keep mental accounts of groups' previous behaviour, in some aggregate form. This mental accounting provides an evolutionary explanation for why humans hold intergroup attitudes (Brewer and Kramer, 1985; Kurzban, Tooby, and Cosmides, 2001). One simple descriptive framework is that groups, like individuals, are perceived on the two dimensions of warmth and competence (Fiske, Cuddy, and Glick, 2007). Our model captures the warmth dimension. It also shows why a group-level measurement can be cognitively as important as individual-level characteristics: when humans are group-reciprocators, aggregated group characteristics (how often that group has cooperated with your group, and vice versa) predict individual behaviour better than individual characeristics (how often you have cooperated with this individual).

Fearon and Laitin (1996) use a repeated-game framework, with two classes of possible equilibria, to explain how different ethnic groups can live at peace.

In their ”spiral regime”, defection by any member of ethnic group A towards a member of B leads to subsequent defection by all members of B towards members of A for a fixed number of periods. This is an infinitely repeated game with multiple equilibria. The goal is to explain institutions which support interethnic cooperation; the spiral regime is analogous to institutions like feuds. Our theory has a different setup and motivation. We examine the evolutionary stability of different types in a finitely-repeated game. In Fearon and Laitin, cooperation is supported by the threat of collective punishment. In our model, group reciprocity is evolutionarily stable because individual free-riding is balanced against group selection. So, our model is designed to explain the evolution of ”strong” reciprocal motivations in humans (Gintis, 2000), rather than the stability of institutions supporting interethnic peace. Ultimately, it is an empirical question whether intergroup peace and conflict are best explained by rational-actor models, psychological models with ”strong” reciprocity, or a combination of both.

3. Model

We consider a mixed population of two types, selfish and group reciprocators (GR). At the beginning of each generation, the population randomly divides into a large number of groups of size G each. Let p denote the population share of GR types. Let p_g be the proportion of GR in group g, which is distributed binomially.

At every step t, everybody interacts with everybody. In each pair, each individual chooses between cooperation and defection. Cooperation entails a cost c to the cooperator and a benefit b to her partner. Defection carries no costs. That is, each pair plays the following Prisoner's Dilemma game:

	Cooperate	Defect
Cooperate	$b-c$	$-c$
Defect	b	0

Selfish types always defect, A GR individual i starts by cooperating, and then cooperates with all individuals belonging to group g with a probability $\phi(l_{gi})$, where l_{gi} is the proportion of individuals from group g who cooperated with individual i in round $t-1$. $\phi(\cdot)$ is monotonically weakly increasing. We consider the cutoff strategy:

$$\phi(l_{gi}) = \begin{cases} 1 & \text{if } l_{gi} \geq k \\ 0 & \text{otherwise.} \end{cases}$$

Equilibrium in this game is as follows: in period 1, group reciprocators help everyone. In period 2, all group reciprocators help those in "supraliminal" groups with $p_g \geq k$. In periods 3 and above, group reciprocators in supraliminal groups help those in supraliminal groups; they defect against everyone else, and all other individuals defect.

The fitness is the payoff at the limit where $t \to \infty$. Equivalently, since the game always settles to a stationary action profile, it is the average payoff of T rounds when $T \to \infty$.

Individuals' fitness therefore depends only on whether they are in a "supraliminal" group, and on their type. Let q be the proportion of supraliminal groups. Let $\bar{p}$ be the proportion of GR individuals in supraliminal groups (out of the total population in such groups). Let $\underline{p}$ be the proportion of GR individuals in subliminal groups (out of the total population in such groups). It follows that

- Group reciprocators in supraliminal groups get a payoff of $\bar{p}qb - qc$.
- Selfish types in supraliminal groups get $\bar{p}qb$.
- Group reciprocators and selfish types in subliminal groups get 0.

After each generation, reproductive success is proportional to fitness, the total population size stays the same, and children are remixed randomly into new groups of the same size. The mean fitness of the GR type is

$$\frac{\bar{p}q(q(\bar{p}b - c))}{p}$$

and the mean fitness of selfish types is

$$\frac{(1-\bar{p})q(q\bar{p}b)}{1-p}$$

After rearranging, the mean fitness of reciprocators is higher if

$$\frac{\bar{p}-p}{1-p} \geq \frac{c}{b}. \tag{1}$$

where

$$\bar{p} = E[p_g | p_g \geq k] = \frac{1}{G}\frac{\sum_{l=kG}^{G} l\text{Binom}(l,G,p)}{\sum_{l=kG}^{G}\text{Binom}(l,G,p)}$$

The LHS of (1) is decreasing in p and is equal to the threshold k when $p = 0$.[2]

Proof. We will first prove an auxiliary lemma and then the main result.

Lemma 1. *Let $x_1, x_2, ..., x_n$ be iid Binomially-distributed variables with probability of success p, and let $x_i = 1$ denote the event where x_i fails. Then showing that $\frac{\bar{p}-p}{1-p}$ decreases in p is equivalent to showing that $\frac{p(x_1=1|S_n \leq k)}{p(x_1=1)}$ increases in p, where $S_n = x_1 + x_2 + ... + x_n$.*

Proof of Lemma 1

First note that proving that the LHS of (1) is decreasing in p is equivalent to proving that $1 - \frac{\bar{p}-p}{1-p} = \frac{1-\bar{p}}{1-p}$ is increasing in p. Second, note that $1-\bar{p}$ captures the expected proportion of failures of a Binomially-distributed variable given that the proportion of successes was at least k, or, put differently, given that the proportion of failures was at most k. Finally, we can replace the expected proportion of failures with the probability of a failure. All in all, we get that proving that $\frac{1-\bar{p}}{1-p}$ is increasing in p is equivalent to showing that $\frac{p(x_1=1|S_n \leq k)}{p(x_1=1)}$ is increasing in p.

Proving the main result

Lemma 1 implies that if $x_i = 1$ denotes the event where x_i fails, and S_n counts the number of failures among n trials, then we need to show that $\frac{p(x_1=1|S_n \leq k)}{p(x_1=1)}$ increases in the probability of success p. For tractability, we will now revert

[2]When the share of GR in the population is very small, the probability that $p_g = k$ conditional on $p_g \geq k$ goes to one.

to the more standard notation of $x_i = 1$ as denoting the event where x_i *succeeds* (s.t. S_n counts the number of successes among n trials), and show that $\frac{p(x_1=1|S_n \le k)}{p(x_1=1)}$ *decreases* rather than increases in the probability of success p.

Proof

$\frac{p(x_1=1|S_n\le k)}{p(x_1=1)} = \frac{p(s_n\le k|x_1=1)}{p(s_n\le k)} = \frac{p(s_{n-1}\le k-1)}{qp(s_{n-1}\le k)+pp(s_{n-1}\le k-1)}$

$= \frac{p(s_{n-1}\le k-1)}{q(p(s_{n-1}\le k)-p(s_{n-1}\le k-1))+p(s_{n-1}\le k-1)} = \frac{p(s_{n-1}\le k-1)}{qp(s_{n-1}=k)+p(s_{n-1}\le k-1)}.$

Using a known result,[3] according to which

$$p(s_n \le k) = \frac{n!}{(n-k-1)!k!}\int_0^q t^{n-k-1}(1-t)^k dt = \frac{n!}{(n-k-1)!k!}\int_0^1 q^{n-k}s^{n-k-1}(1-qs)^k ds,$$

we get that $\frac{p(x_1=1|S_n\le k)}{p(x_1=1)}$ is decreasing in p if and only if $\frac{q\binom{n-1}{k}p^k q^{n-k-1}}{\frac{(n-1)!}{(n-k-1)!(k-1)!}\int_0^1 q^{n-k}s^{n-k-1}(1-qs)^{k-1}ds}$ is decreasing in q, i.e., if and only if $\frac{\binom{n-1}{k}p^k}{\frac{(n-1)!}{(n-k-1)!(k-1)!}\int_0^1 s^{n-k-1}(1-qs)^{k-1}ds}$ is decreasing in q. Thus, it is sufficient to show that $\int_0^1 s^{n-k-1}(\frac{1-qs}{1-q})^{k-1}\frac{1}{1-q}ds$ is increasing in q. Since $(\frac{1-qs}{1-q})^{k-1}\frac{1}{1-q}$ is non-decreasing in q for every $s \in [0,1]$, the proof is complete.

□

It follows that there is a unique ESS with a positive share of group reciprocators if and only if $k > \frac{c}{b}$. Otherwise the population is homogeneously selfish in the unique ESS.

4. Simulations

The model includes two simplifying assumptions: a large number of groups, and a large number of rounds T in each generation. To check how these simplifications affect the result, we run simulations. We use the following sets of parameters: $c/b = 0.2, 0.5$; $T = 10, 20$; N groups = 10, 50; $k = 0.4, 0.8$. This gives

[3] See equations (3) and (4) in https://mathworld.wolfram.com/BinomialDistribution.html.

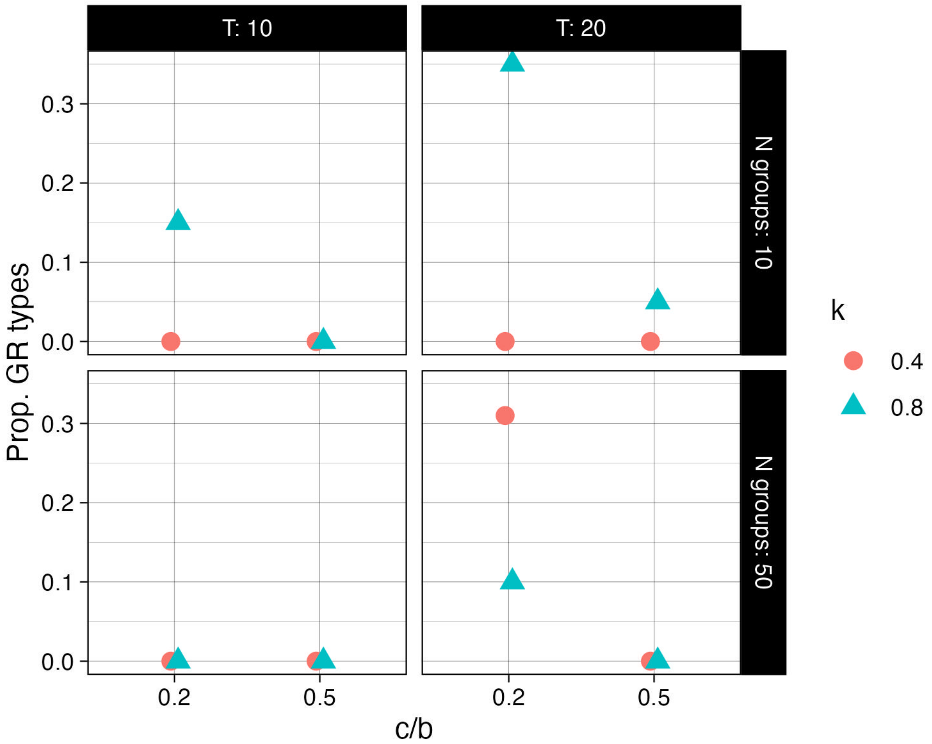
16 unique combinations of parameters. We always set $G = 8$ and start with half the population as GR types. Fitness is normalized so that the "sucker's payoff" $-c$ equals zero. For each combination we run 20 experiments, each lasting 500 generations. After 500 generations we record the proportion of group reciprocators.

Figure 1 shows the mean proportion of GR types across all experiments for each combination of parameters. For all combinations of parameters but one, either GR types or selfish types always went to fixation within 500 generations. In these cases, the proportion of GR types is just the proportion of experiments where GR types went to fixation.

A shorter number of periods T leads to fewer GR types, as expected since it gives more weight to the early-round losses of GR types. The number of groups does not seem to affect the evolution of GR types. As expected, a higher cost-benefit ratio c/b leads to fewer GR types. A higher threshold k also usually leads to more GR types, and in particular when $k < c/b$, group reciprocity never evolves. One exception is with 50 groups and $T = 20$: in this case, more group reciprocators evolve when $k = 0.4$. This is also the sole parameter combination where not all experiments went to fixation.

In our analytic result with many groups, group size G doesn't matter. With finite numbers of groups, all groups may fall below the k-threshold in a given generation. This becomes more likely when G is large and when the population proportion of GR types is below the threshold (because when G is large, the proportion of GR types in each group becomes concentrated on the population proportion). So, group size may matter. We ran one further parameter set to check whether group reciprocity could be stable in larger groups. We set $G = 40$, N groups = 40, $T = 20$, $k = 0.6$ and $c/b = 0.1$. In 10 experiments, the proportion of group reciprocators was always between 60 and 70 per cent after 500 generations. So, evolution of group reciprocity is possible even with large groups, although it seems to require high benefit-cost ratios.

Figure 1: Simulation results. Plots show proportions of group reciprocator types after 100 generations.



5. Conclusion

We introduced an evolutionary model of group reciprocity. Group reciprocal motivations can evolve under plausible parameter values for human populations [XXX can we say that?]. Evolved group reciprocity could explain why humans track group-level reputations. It also provides a simple way that upstream reciprocity can evolve.

The simplest alternative theory of group reciprocity is perhaps that many groups are able to solve collective action problems, i.e. to incent or persuade their members to maximize the payoff of the group. If so then reciprocity towards other groups could be optimal in the same way as individual-level reciprocity. Lab experiments show group reciprocity even among ”minimal” groups which have no way to address collective action problems. But this might be because participants over-generalize, bringing into the lab their intuitions about behaviour that makes sense in the field. A useful next step would be to examine group reciprocity in the field, among groups which lack institutions for collective action.

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