


The Evolution of Ostracism in Human Societies

Graham Alexander Noblit,^{a,b,*}, Joseph Henrich^c

^a*Schwartz Reisman Institute, University of Toronto, 661 University Ave Suite 710, M5G 1M1, Toronto, Ontario, Canada*

^b*Vector Institute, 101 College St Suite 230-4, M5G 1L7, Toronto, Ontario, Canada*


^c*Department of Human Evolutionary Biology, Harvard University, Museum of Comparative Zoology, 26 Oxford Street, Cambridge, Massachusetts, USA*

Abstract

Understanding how humans successfully stabilize public good contributions is a major ongoing question in the social and behavioral sciences. The use of targeted sanctions against defecting strategies is an important solution to this problem. However, ethnographic and behavioral evidence suggest that punishment is sometimes not used against defectors to stabilize cooperation. Punishment instead is either light and likely insufficient to incite cooperation or takes the form of verbal repudiations urging defectors to reform their behavior. Should defectors not reform, they are then ostracized from groups. We construct a cultural evolutionary game-theoretic model to evaluate the evolutionary viability of ostracizing strategies. We demonstrate that simple ostracizing strategies are unlikely to be evolutionarily viable and can neither encourage the evolution of contrite-defectors, who respond to punishment with cooperation nor invade recalcitrant-defecting populations, which ignore punishment. Motivated by the ethnographic literature, we then consider a hybrid sanctioning-ostracizing strategy that lightly-sanctions defectors before ostracizing repeat defectors. Such a strategy demonstrates clear advantages over simple sanctioning strategies as they have been previously modeled. It increases average fitness because it can afford to impose light-sanctions when common, because sanctions are irrelevant for coercing future cooperation from defectors. More so, when recalcitrant defecting strategies have some possibility of arising in a population, sanctioning-ostracizing strategies dominate pure sanctioning ones, again stabilizing cooperation with greater efficiency. Finally, our model makes psychological predictions concerning the reasoning processes that defectors will go through when defectors are coerced to cooperate by the threat of ostracism as opposed to sanctioning.

Keywords: Cultural Evolution, Public Goods, Norms, Game Theory, Ostracism, Anthropology

*Corresponding author

Email address: graham.noblit@utoronto.ca (Graham Alexander Noblit,)

1. Introduction

Somewhat infamously, Jane Briggs, in her ethnographic work Briggs's (1971) with the Utku Inuit, emphasizes her inability to understand and conform to Utku norms. Repeatedly, Briggs expresses her displeasure and anger, often directed at others; failed to sufficiently engage in social events and to engage with others in expected and normatively appropriate ways; and was generally considered by others to repeatedly prioritize her own interests over the other individuals' and the community's. Though Briggs' Utku hosts recognized her non-Utku background and were immensely tolerant and accommodating of her behavior, they repeatedly expressed subtle, and to Briggs, imperceptible, cues of their dissatisfaction. Briggs rarely, if ever, faced costly and targeted sanctions for her behavior. Instead, her social partners calmly and patiently prompted her to reform her behavior and conform to the community's norms and community members' expectations. When Briggs proved incapable of doing this and her behavior imposed too large of a cost on the community that her hosts could not bear, she was still not targeted with sanctions. Instead, they simply ceased to visit and socialize with her and encouraged her to not visit them, physically isolating themselves from her. In a word, Briggs was ostracized. Consequently, Briggs lost access to various opportunities to communicate, cooperate, and coordinate with, as well as learn from, her hosts. In fact, Briggs was even unsure whether she would be invited to participate in the Utku's seasonal migration, a collective movement that was critical to adaptive life in the region. Because Briggs failed to possess the requisite acumen permitting her to internalize her hosts' repeated hints prior to her ostracism as to just how inappropriate, rude, and inconsiderate her behavior was, she was unable to reform her behavior and as such, was considered something of a lost cause, best dealt with by avoidance.

Briggs' frank and vulnerable portrayal of her ostracism as a result of her an-

tisocial behavior provides readers with an in depth portrayal of how community-members in a small-scale society may handle individuals who fail, be it because of unwillingness or inability, to conform to normative standards. Of course, both her ostracism and how she was treated prior could be a unique result of her status as an anthropologist and visitor to the Utku community, however, many similar examples of ostracism are well-documented. Smith (1961) describes a process in a Japanese paddy-rice farming village whereby norm-violators are first ridiculed and then ostracized if verbal sanctions fail to incite cooperation. Hoebel (1936) documents cases of ostracism and individuals' concerns about ostracism, should they be labeled norm-violators, in Plains Amerindian societies. Among the Igbo of West Africa, Amadiume (2015) describes how men who failed to conform to norms concerning contributing to public goods established by their lineage, such as contributing money towards medical care or the construction of houses, would be fined. If norm-violators refused to pay their fines then they were summarily ostracized and "when such a man died, no one bothered about him – he died like a dog" (Amadiume, 2015, p. 58). In all of these cases, norm-violators are initially provided with signals or light-sanctions communicating that their behavior is unacceptable. Should norm-violators fail to reform their behavior, they are then ostracized from the community. Sanctions in these cases largely take a rather specific form, exclusion from a community.

In the above ethnographic cases, understanding how humans are able to stabilize costly-norms, particularly those concerning public goods, requires understanding the evolutionary dynamics of ostracism. Because the benefits of public goods fall to all group members, regardless of whether they contributed to the good or not, and, in the case of linear public goods, the cost of contribution to the good is larger than the marginal benefit derived, defection is the well-known dominant strategy in linear n -player prisoner dilemmas or public good

games (Boyd and Richerson, 1988; Olson, 1971; Samuelson, 1954; Taylor, 1987). An important class of models considers the use of costly-sanctions targeted at defectors which, in reducing defection’s strategic-dominance, can stabilize public good contributions (Boyd et al., 2010; Boyd and Richerson, 1992). There is extensive empirical evidence for the use of sanctions to enforce cooperation (Chaudhuri, 2011; Fehr and Fischbacher, 2004; Fehr and Gächter, 2000; Herrmann et al., 2008; Mathew and Boyd, 2011, 2014). However, experimental field evidence indicates that although third-party punishment of defectors is observed to some degree in all studied societies, the observed amount culturally varies and, in some cases, is insufficient to stabilize cooperation; this finding suggests that distinct punishment institutions or norms may stabilize cooperation across societies (Henrich et al., 2006). Distinct forms of norm-stabilization, i.e. distinct behaviors, will require distinct information criteria for norm-enforcers to be able to stabilize equilibria, in turn constructing distinct social environments for individual psychological development, producing distinct proximate cooperative and punitive psychologies (Chudek and Henrich, 2011; ?; Henrich and Henrich, 2014). Understanding ethnographic evidence of how humans stabilize public goods, but also human cognitive and affective variation more generally (Chudek and Henrich, 2011), requires studying the evolutionary dynamics and equilibrium conditions of different forms of punishment.

While much attention, appropriately, has been paid to the importance of costly- and targeted-sanctions to understand how humans stabilize public goods contributions, costly-norms, and solve the problem of defection in large-scale cooperative social dilemmas (Boyd, 2019; Boyd and Richerson, 2022). Baumard (2010), however, has argued that ostracism is a better representation of ethnographic descriptions of punishment as compared to direct-sanctions, though it is not clear whether ostracism refers to behavior in a group-setting or some dyadic

conception of partner-choice. Importantly, the ethnographic cases described above demonstrate a conspicuous absence of third-party sanctions as targeted acts of individuals accepting costs to impose harms on norm-violators. Instead, we are presented with low-cost sanctions or even verbal reprimands (which may be costly to an organism characterized by a specific affective proximate psychology) that provide defectors with an opportunity to alter their behavior. Even in the Igbo case where fines are imposed, they do not take the form of seizing property should the fine not be freely offered up (Amadiume, 2015) and instead, individuals who do not signal their willingness to cooperate by paying the fine are simply ignored (for an explanation of other aspects of this case, see Panchanathan and Boyd, 2004). The absence of targeted sanctions poses something of an explanatory quandary; if defection is the payoff-maximizing course of action and best-response to cooperation absent additional mechanisms, then cooperators should not waste their time trying to reform defectors because defectors would only ever do worse should they commence cooperating. Instead, cooperators must isolate defectors from the benefits of cooperation, which is difficult in a public good case, or impose costs on defectors in order to both eliminate defection’s payoff-dominance and provide cause for defectors to begin to cooperate. Why cooperators attempt to reform defectors without punishing them directly and why defectors would in turn begin to cooperate requires further explanation.

Brigg’s experience suggests that ostracism is the important mechanism stabilizing cooperation in public goods social dilemmas. We define ostracism as the exclusion of individuals from group membership either through physical or social isolation. While previous models (Hirshleifer and Rasmusen, 1989; Sasaki and Uchida, 2013) of ostracism exist, and have studied how ostracism stabilizes public good contributions, these models fail to acknowledge two important issues.

First, the evolutionary viability of ostracism appears to be heavily frequency-dependent and extant models, alongside other discussions of ostracism (Baumard, 2010; Boyd, 2019), do not consider this fact. If one is the lone ostracizer in a population then one merely self-ostracizes. It is not clear that strategies that merely ostracize defectors can proliferate when rare, because individuals, or assuming some degree of assortment, small cohorts of individuals, generally do not see a net-benefit in contributing to linear public goods alone. Second, extant models do not acknowledge humans’ obligatory social nature. Evolutionary biologists and ecologists consider sociality to evolve under conditions where group-life confers individuals with benefits that exceed the costs of sociality, such as increased food-competition and parasite-exposure and -stress (Krause and Ruxton, 2002). Benefits of sociality include numerous mutualisms, such as predator dilution, whereby, assuming well-mixed groups, the probability of an individual being encountered by a predator approximately scales inversely with group-size (Foster and Treherne, 1981; Krause and Ruxton, 2002); pair-wise cooperation, stabilized by kinship or reciprocity (Fudenberg and Maskin, 1986; Hamilton, 1964; Park et al., 2022); and exposure and access to information possessed by group-members (Krause and Ruxton, 2002). We label any net-benefit associated with group-life, excluding the specific public good dilemma that we model, “group-externalities”. In the language of neoclassical economics, societal membership entails access to a club good whereby the good’s associated benefits are non-rivalrous but still excludable (Buchanan, 1965); ostracism is the process by which individuals are excluded from accessing these benefits. However, frequency-dependence again rears its head—when ostracizing strategies are rare, self-ostracism means abandons the benefits of living in groups.

In the human case, we might consider the benefits of living in groups to generally, though perhaps not always (Rivière, 1984), be relatively large. Hu-

mans are not born with innate knowledge permitting many of basic adaptive resource- and shelter-production behaviors, and instead rely on socially inherited information for individual survival (Boyd, 2019; Boyd et al., 2011; Chudek and Henrich, 2011). A reliance on information held by others extends beyond learning how to construct and use material-technologies or exploit physical environments (McClellan and Denniston (1981); Ridington (1982, 1988)). Norms entailing cooperating and coordinating with group-members are often critical to permitting survival not only in social environments but physical ones (Ridington, 1988, provides a particularly interesting ethnographic example). Much of human adaptation also comes through group-behavior, i.e. the various norms and institutions which permit humans to pool risk and resources, such as meat-sharing (Chudek and Henrich, 2011; Kelly, 1995; Wiessner, 1982). Such institutions may themselves not be public goods or may be public goods defined by a high benefit-to-cost ratio and correspondingly easily stabilized through any of several mechanisms including reciprocity in small groups (Boyd and Richerson, 1988); costly-signaling (Gintis et al., 2001); and punishment, be it self-interested (Panchanathan and Boyd, 2004), coordinated (Boyd et al., 2010), or decentralized (Boyd and Richerson, 1992). Additionally, resources in the environment may follow hard to estimate or even non-stationary distributions, a significantly difficult learning problem for individuals (Sutton and Barto, 2018). As one might expect, food and water sources are a consistent topic of conversation in small-scale societies (Johnson and Earle, 1987; Wiessner, 2014). Humans’ access to mating opportunities also depends on access to social groups. And finally, in the pairwise case, human linguistic abilities permit considerably more dyadic cooperation than observed in other primates, either because we can track reputation with greater fidelity or can aggregate information to correct perception errors in cooperative dilemmas (Boyd and Mathew, 2021; Nowak and Sigmund,

2005; Wiessner, 2014). The presence of these various easily stabilized forms of cooperation suggests that group-membership in human societies provides extremely large benefits to individuals, independent of public goods. However, recalling Briggs’ fear that her community might abandon her to the harshness of the wilderness, the exact nature of these benefits, for any given population, will additionally depend on ecological parameters relative to a culturally evolved toolkit of technological, social, and ecological know-how.

To provide clarity on the study of ostracism, we formalize a cultural evolutionary game-theoretic model of ostracizing strategies in a n -player linear public goods game. Unlike previous models, we formalize the role of group-membership on agents’ payoffs. Using this model, we will show that even though we observe ostracism in the ethnographic record, simple ostracizing strategies have essentially no invasion potential and thus are not evolutionarily viable. This result suggests that ostracism is not distinct from costly-punishment strategies, but rather best understood as a specific form of punishment. We then study a strategy that punishes defectors prior to ostracizing repeat-defectors, which we label **Sanctioner-Ostracizer**. We show that such strategies are far more efficient than strategies that only sanction defectors. Such **Sanctioner-Ostracizer** strategies also alter the reasoning that defectors will go through when considering whether to reform their behavior and begin to cooperate.

2. Model

2.1. Description

The model follows standard n -player evolutionary game theoretic models. Groups of size n are sampled randomly from an effectively infinite and perfectly mixed population. Agents face two decision contingencies: a linear public goods game and an ostracizing opportunity. Because group-size changes within

the course of an individual's lifetime, we must establish whether the benefit of the public good, b , is constant with respect, or proportional, to the initial group-size, n (Boyd and Richerson, 1988). In the former case, should m cooperating-ostracizers exist in a group then, following ostracism, these m individuals will still receive the full benefit of the public good; in the latter case the m cooperating-ostracizers will receive only a fractional-benefit, $\frac{m}{n}$, of the public good. Because the latter case provides more stringent conditions for the evolution of cooperators, we assume it; it also permits closed-form solutions when studying replicator dynamics. Note that adopting this formalism means that the full benefit of our public good can only be accessed when all members of the original group, prior to the occurrence of any ostracism, contribute and that this assumption does not match all empirical cases. These assumptions mean that agents can contribute $\frac{b}{n}$ to a public-good at cost c to themselves. Cooperators thus contribute $\frac{b}{n}$ to each group-member in their *current* group where n is the *original* size of groups.

The second contingency is an ostracizing opportunity where individuals can choose to ostracize group members. Ostracizing entails ejecting others from the group at cost h per ostracized individual. Ostracism is always successful and ostracized individuals form a second sub-group. For example, a group of size n with m ostracizing agents and $n - m = s$ ostracized agents will split into two groups of size m and s . Groups are isolated from one another and sub-groups formed after any occurrence of ostracism do not interact in any way. Groups continue to exist after each round with probability ω and all actions are fully observed by all group-members.

Agents' payoffs are a function of both the public good outcome and the size of their group mediated by what we label a "group-externality function". Such functions are commonly used in evolutionary ecology to understand the

evolution of sociality and, among non-human animals, their parameters are considered to be defined by ecological and organismal factors. Group-externality functions are generally assumed to both display decreasing marginal returns, being concave with a negative second derivative, and to possess a single maximum, the optimal group-size (Krause and Ruxton, 2002). Note that ecological work, empirical and theoretical, indicates that group-size generally exceeds optimal levels (Krause and Ruxton, 2002). We ignore this issue as doing so does not facilitate ostracism’s evolution in any way.

We study group-externality functions that take two functional forms. Equation 1, provides a linear function of current group size and although a constant marginal effect of changing group size is unrealistic, the affine form permits closed-form fitness equations.

$$\Gamma(x) = \alpha + \beta(x - 1) \tag{1}$$

Here, $\Gamma(x)$ is the group-externality effect on a focal agent’s payoff as a function of living in a group of size x with $x - 1$ other individuals. When $x = 1$, the focal agent lives alone receiving a payoff of α . The coefficient, β , denotes the constant marginal effect of increasing group size. Because groups in this model never exceed their initial size, n , we assume that this linear functional form is only defined for the domain $1, \dots, n$.

Equation 2 provides a second, non-linear functional form, which, although is more realistic, prevents us from constructing closed form solutions to fitness functions. Again, x indicates the number of individuals in the current group, including the focal agent, and n is the initial group size. The coefficients α and γ represent the payoff effect of living alone or in a full group of size n respectively and the term $\gamma - \alpha$ represents the payoff effect of a focal agent being isolated from a full-sized group. The constant, $\phi \in (0, 1]$, alters Γ ’s concavity for fixed α

and γ values. As ϕ decreases from 1, Equation 2 becomes increasingly concave (see Figure 1). This concavity formalizes the fact that adding an individual to a group of size 2 should have a significantly larger impact on all group-members' payoffs when compared to adding an individual to a group of size 19 if the optimal group-size is 20.

$$\Gamma(x) = \alpha + (\gamma - \alpha) \left[\frac{x-1}{n-1} \right]^\phi \quad (2)$$

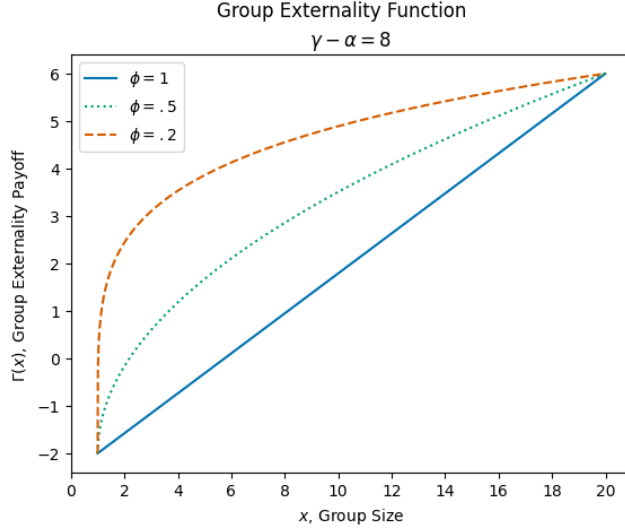


Figure 1: This figure plots various possible group-externality functions. Varying ϕ impacts the concavity of the group-externality function and therefore the non-constant marginal effect of changing group size.

2.2. Strategies

The strategies we consider are **Ostracizer**, labeled **O** who always contributes to the public good and ostracizes defecting strategies at cost to itself, and **Recalcitrant-Defector**, who always defects in the public good, never changing its behavior when ostracized. In Section 3.1 we demonstrate why, un-

like in the canonical Boyd and Richerson (1992) punishment model, **Recalcitrant-Defectors**, labeled **RD**, are the relevant defecting type to consider and not **Contrite-Defectors**, labeled **CD**, who respond to ostracism with cooperation. We then consider a "hybrid" ostracizing strategy, **Sanctioner-Ostracizer**, labeled **SO**, who always cooperates in the public good and sanctions any defecting strategies in the first round before ostracizing any agent that continues to defect in a future round.

Reproduction occurs once payoffs are assigned and is proportional to agents' payoffs. Strategies which earn above average payoffs are more likely to reproduce. No alternative social-learning regimes, such as conformist transmission, are considered. Reproduction then follows standard continuous replicator dynamics.

3. Results

3.1. *Contrite- or Recalcitrant-Defectors*

Following Boyd and Richerson (1992), we first must establish whether **RDs**, who do not cooperate once ostracized, or **CDs**, who do, are the relevant defecting strategy to consider. Consider a basal population defined predominantly by **RDs** and a small proportion of a particularly generous form of **CDs** that, following any act of ostracism, seeks out the ostracizing agent once she has left the group and begins to cooperate with her. Such a mix may exist because, absent any punishing or ostracizing strategies, any initially defecting strategies would have identical expected fitness, and, correspondingly, non-recalcitrant defecting strategies will be able to drift into the population (Boyd and Richerson, 1992). Assume that groups are formed at random and that a naive **O** has some probability of arising in any group, perhaps because of mistakes by either of the basal defecting strategies about the behavioral context of the game being played

(Boyd and Richerson, 1992). In the first round of interaction, the **O** mutant will cooperate then leave the group of defecting types and be isolated. In groups with a single **CD** present, she will free-ride in the first round and then experience one round of the diminished group-externality term as well as the absence of the public good, following which, on the third round, she will leave the initial group and pays a cost of h to find the lone **O** and joins her group, forming a group of size 2. In groups composed only of **RD** and an **O** mutant, a focal **RD** will free ride for one round before experience a group of size $n - 2$ for all future rounds. Note that in this case, because this is a toy model, we assume that a lone mutant ostracizing pays a single cost h to leave a group rather than a cost of $h(n - 1)$ to drive off $n - 1$ other group members. The payoffs, assuming a constant marginal effect of changing group-size, for **CD** and **RD** are as follows:

$$V(\mathbf{CD}) = \frac{b}{n} + \alpha + \beta(n-1) + \omega [\alpha + \beta(n-2) - h] + \frac{\omega^2}{1-\omega} \left[\alpha + \beta + 2\frac{b}{n} - c \right] \quad (3)$$

$$V(\mathbf{RD}) = \frac{b}{n} + \alpha + \beta(n-1) + \omega [\alpha + \beta(n-2)] + \frac{\omega^2}{1-\omega} [\alpha + \beta(n-2)] \quad (4)$$

CD will increase in the population relative to **RD** if and only if:

$$\frac{\omega}{1-\omega} (2\frac{b}{n} - c) > h + \frac{\omega}{1-\omega} \beta(n-3) \quad (5)$$

Verbally, the net life-time benefit associated with the fractional-benefit of the public good must exceed the single-round cost of searching for **O** plus the life-time (partial) loss of the group-externality term due to moving from a group of size n to a group of size 2. This result does not change if we assume that the public good can be fully supplied by only two individuals in which case the

invasion criterion becomes:

$$\frac{\omega}{1-\omega}(b-c) > h + \frac{\omega}{1-\omega}\beta(n-3) \quad (6)$$

We should still not anticipate this criterion to be met and might assume that in most ecologies, group-life, which may contain previously stabilized public goods, is likely far more important than any individual public good. We take this result to indicate that the relevant defecting strategy to consider for **O** is recalcitrant defecting ones and not contrite defectors. Ostracizing strategies cannot distinguish between contrite and recalcitrant defecting strategies.

We now turn to what equilibria exist in an ecology defined by two strategies: **O** and **RD**

3.2. *Ostracizer and Recalcitrant-Defector Ecology*

Two stable equilibria exist, assuming no assortment, when **O** and **RD** compete: either a population composed entirely of **RD** or one composed entirely of **O**. We first examine when **RD** is an ESS (proof in Appendix A.3.2):

$$\frac{\frac{b}{n} - c}{1-\omega} - h(n-1) < \frac{\omega}{1-\omega}\beta(n-1) \quad (7)$$

This criterion must hold; the left-hand-side is negative, by definition, whereas the right-hand-side is similarly positive by definition. Simple ostracizing strategies have essentially no invasion potential as lone mutants because ostracizing mutants simply isolate themselves when rare. When an ostracizing strategies are rare then the choice to ostracize **RDs** is no different from self-ostracism. This is true even if we introduce small degrees of relatedness. So long as the benefit of the public good is small relative to the value of living in groups, which should generally be the case, **O**, even if they invade as a few individuals, will always have worse fitness post ostracism. Note the distinction from sanctioning

strategies, which are assumed to be able to invade as isolated mutants (Boyd and Richerson, 1992), or with reasonable degrees of assortment (Boyd et al., 2010).

If **O** is to avoid self-ostracism, it must coordinate its invasion with others. Coordination among **O** mutants may have synergistic effects with group-externality functions that demonstrate decreasing marginal returns. Assortment will occur when agents rely on social-learning mechanisms that correlate group-members' behaviors, such as if a prestigious (Chudek et al., 2012; Henrich and Gil-White, 2001) adopts an ostracizing strategy. Importantly, prestige-transmission has already been demonstrated to facilitate the evolution of cooperation in groups (Henrich et al., 2015).

To study **O** invasion when the **O** mutant is prestigious and when group-externality functions are nonlinear, we consider the following toy model. Consider an ostracizing mutant that prior to the act of ostracism attempts to convince other agents to adopt her strategy and effectively to become **O**s themselves. She is successful in the venture with probability, r . If $r = 0$ then the **O** mutant can convince nobody and will attempt to invade the population alone. If $r > 0$, the invading mutant will, in expectation, assort with $r(n - 1)$ other **O**s.

Under the above assumptions, an ostracizing mutant can invade (**RD** is not an ESS) so long as (proof in Appendix A.3.2):

$$\begin{aligned}
 & -h(n-1)(1-r) + \frac{\omega}{1-\omega} \left[\frac{b}{n}(n-1)r + \alpha + (\gamma - \alpha)r^\phi \right] \\
 & > \\
 & \frac{c - \frac{b}{n} + \gamma}{1-\omega}
 \end{aligned} \tag{8}$$

The left-hand-side of Equation 8 consists of the cost of expelling the $(n-1)(1-r)$

individuals who the mutant **O** failed to persuade plus the life-time derived benefit of the persuaded individuals' contributions to the public good, $\frac{b}{n}(n-1)r$, and the group-externality payoff of the corresponding group size, $\alpha + (\gamma - \alpha)r^\phi$. Note that as ϕ approaches 0, and the group-externality function becomes more concave, $r^\phi \in [0, 1]$ is inflated. The right-hand-side of the criterion includes the life-time net-cost of the public good and the group-externality payoff associated with a full-group, what the invading mutant loses out on. If we consider humans to be a long-living organism, then the $\frac{1}{1-\omega}$ terms will dominate and we are presented with a slightly more manageable form:

$$\begin{aligned} & \frac{b}{n}(n-1)r + (\gamma - \alpha)(r^\phi - 1) \\ & > \\ & \frac{1}{\omega} \left(c - \frac{b}{n} \right) \end{aligned} \tag{9}$$

Essentially, assuming $\frac{1}{\omega} \approx 1$, indicates that derived benefits of the ability of the invading mutant to encourage prestige in its group, $\frac{b}{n}(n-1)r$, must exceed the net-cost of contributing to the public good, $c - \frac{b}{n}$, and the loss of prestige-inflated group-externality payoff ($r^\phi - 1 < 0$).

It is difficult to interpret when the above criteria are met. Therefore, Figure 2 plots the necessary combination of ϕ and r values that satisfy the full form of the invasion criterion, Equation 8, in three separate ecological environments: $\gamma - \alpha \in \{4, 8, 16\}$ for two values of $b \in \{3, 6\}$ when $c = 1$. Figure 2 indicates that **O** invasion requires unreasonable degrees of prestige unless the group-externality function is highly concave. For example, when $\phi = .5$, an invading **O** mutant must successfully convince others with a probability of about .4 in the most benign ecology, but about .8 in the harshest ecology ($b = 3, n = 20$). We might generally consider human ecologies to be harsh. Human adaptation to the environment largely occurs as a result of social processes and through extracting

Concavity & Prestige Permitting Ostracizer Invasion

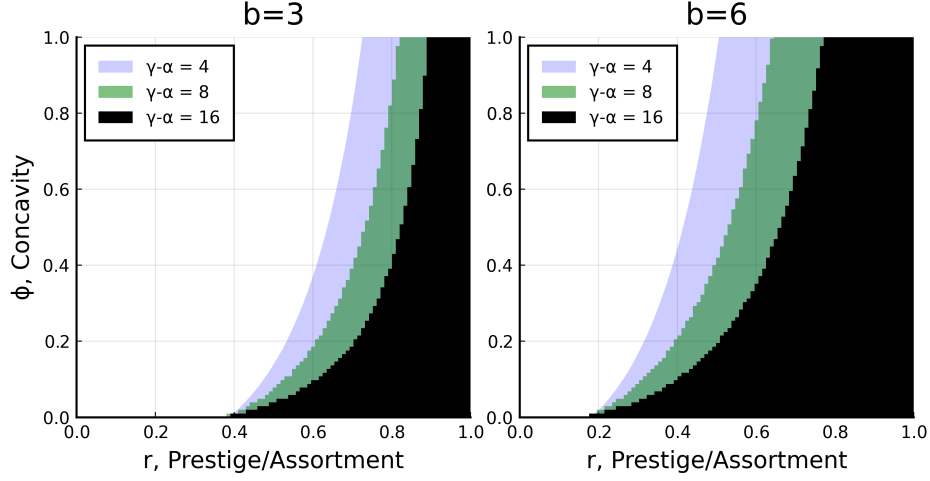


Figure 2: The shaded areas indicate the combination of r and ϕ values permitting **O** invasion for different ecologies, $\gamma - \alpha$. The left plot denotes a public good of value 3 and the right plot one of value 6. In both figures, $c, h = 1$ and $\omega = .98$ and $n = 20$. While prestige transmission and non-linear group-externality functions facilitate **O** invasion in obliging ecologies (small $\gamma - \alpha$), harsher ecologies require either unrealistically concave group-externality functions (low ϕ) or highly prestigious individuals (high r).

information from others' minds (Boyd, 2019), indicating that group-life is associated with large benefits that even adults familiar with an ecology may have difficulty matching should they be ostracized. While decreasing marginal returns to the group-externality function and strategy assortment do facilitate the evolution of ostracism, these factors do not fundamentally alter the difficulty that ostracizing strategies have when invading a **RD** population. This result poses somewhat of a quandary. Under our invasion assumptions, ostracism should not be observed, yet it is repeatedly described in the ethnographic record. How then might ostracism emerge?

Finally **O** is an ESS so long as (proof in Appendix A.4):

$$\gamma - \alpha + \omega b > c \quad (10)$$

This criterion assumes the n is large and that $\omega \approx 1$. Interestingly, unlike Boyd and Richerson’s (1992) punishing-cooperating strategy, the stability criterion of **O** is not only guaranteed, but also entails the single-round group-level benefit associated with the public good, $\gamma - \alpha + \omega b$. The left-hand-side is the cost of being ostracized plus the benefit of the public good on the second-round; the right-hand-side denotes the cost of cooperation. This would seem to contradict the various models in cultural evolution that indicate that punishment can stabilize norms irrespective of their benefits Boyd and Richerson (1992); Gintis et al. (2001); Panchanathan and Boyd (2004), however, this is too strong of a claim. First, it aligns with the stability criterion in Boyd and Richerson’s (1988) model of reciprocity in groups, which does contain a group level benefit term for the public good. Akin to that model, ostracism has similarly low-chances of invading, as discussed in Appendix A.3.1 and Appendix A.3.2, making the importance of a stability criterion of limited relevance. Secondly, it is important to note that the criterion is always met regardless of the value of b . Even though the group level benefit of the public good is included in the criterion, it does not indicate that the group level benefit needs to be particularly positive, i.e. that the stabilized behavior must be adaptive or prosocial. We have not entirely escaped the world where punishment stabilizes a set of behaviors arbitrary of their benefits.

A reasonable argument is that when **O** are the resident type, recalcitrant forms of defection are obviously irrelevant, though they may mutate into the population for various reasons. Contrite forms of defection may also arise. Limited reasoning capacities, which we discuss further in Section 3.3.2, would suggest that a **RD** would recognize its situation once it experiences life outside the group and seek out the group of $n - 1$ **O** to make amends. Documented cases of norms about ostracism that permit norm-breakers to re-enter a community

after a given period of ostracism exist. Hoebel (1936) describes how among an Amerindian Plains group, a woman was found guilty of aborting her child was banished for a temporary period (specifically, until the proper rituals had been conducted). The reasoning behind this norm was that the actions of a norm-breaker sullied them in some way. In the case of murder, the murderer was thought to become "rotten" inside, making "his very breath ... putrid" and his body give off "a bad smell" that would drive away game (Hoebel, 1936, p.436). It was only once the appropriate rituals were required to purify the tribe as a whole that the woman was permitted to re-enter the group. In the case of a murderer, such a norm of banishment may permit a blood-feud to play out outside of the community, i.e. for the norm-breaker to be assassinated by the victim's kin, limiting threats to tribal welfare and negative-externalities for the remainder of the community. Such an explanation, as Hoebel concedes, cannot apply in the case of an abortion whereby no obvious threat of blood-feud exists.

Assume that a **CD** mutant defects on the first round of interaction, is ostracized for one period, and then pays a cost, c_D , to return to the community and that **O** permits the defector to re-enter the community. **O** is stable to a contrite defecting mutant's invasion so long as (proof in Appendix A.5):

$$\omega(b + \gamma - \alpha + c_D) > c(1 - \omega) - \frac{b}{n} \quad (11)$$

Verbally, **O**'s experience of the public good for a single round, which **CD** lacks while ostracized, plus the mutant **C**'s loss of the group-externality term for that same round and the cost to re-enter the group, must exceed the net-cost of cooperation. Again, this criterion will always be met. Though the public good benefit term, b , again shows up in the criterion, it still exists alongside $\gamma - \alpha$. Under the reasonable assumption that $\gamma - \alpha \gg b$ (though this may not always be the case) then the magnitude of the b term, or even its sign, is

of limited significance for satisfying the criterion. In other words, both of the stability criteria above indicate that ostracism, because it so effectively stabilized behaviors, can stabilize behaviors relatively arbitrarily.

3.3. *Sanctioner-Ostracizer and Recalcitrant-Defector Ecology*

As previously discussed, ethnographic cases of ostracism often emphasize that prior to being expelled from the community, actors often, albeit not always, exert some degree of effort to reform defectors, using either verbal reprimands or low-cost sanctions. It is only when defectors continue to defect that they are ostracized. We now consider an ostracizing strategy that initially targets defectors with sanctions and then, should they not begin to cooperate, ostracizes them. Such a strategy should permit ostracism to differentiate between contrite defecting types that will cooperate once given reason to do so and recalcitrant defecting types that impose costs on their groups. We demonstrate that these **SO** strategies are far more efficient at stabilizing cooperation than previously modeled simple sanctioning strategies (Boyd and Richerson, 1992), which we label **S**, and that, interestingly, **SO** also encourages a distinct line of reasoning among agents considering whether to cooperate or defect once punished.

3.3.1. *Sanctioner-Ostracizer Invasion*

Consider a society where a standard sanctioning-cooperator (**S**), as modeled by Boyd and Richerson (1992), has stabilized contributions to some public good. Individuals in this society receive the full net benefit of the public good every round, a payoff of $\frac{b-c}{1-\omega}$. Should any **CD** mutants arise and defect, testing the stability of the status-quo, each of the community members punishes this defecting mutant k units. Previous work (Boyd and Richerson, 1992) demonstrates that so long as the cost of being sanctioned by the group exceeds the

net-cost of cooperation, $c - \frac{b}{n}$, then cooperation is stable:

$$(n - 1)k > c - \frac{b}{n} \quad (12)$$

Now consider when a **RD** mutant arises rather than a **CD** mutant. Such a mutant may represent non-best-response play or perhaps the endogenous results of cultural evolution, representing an agent for which the above criterion does not hold; their experienced cost of punishment may not exceed their experienced net-cost of cooperation, either because they are immune to the extant punishment technology or because cooperating imposes abnormally large costs on them. Such an agent may arise endogenously as individual or sub-group based differences emerge over time that limit the coercive ability of previously successful sanctions. For example, imagine that punishment in this society takes a specific form of economic sanctions, such as the burning of one's rice fields. The presence of a previously stabilized public good, such as irrigation infrastructure, may produce sufficient and sufficiently stable surpluses such that individuals may economically diversify, producing group-members who gain a significant proportion of their living from logging or some form of trade instead of rice-agriculture. Such endogenous changes are exactly what occurred in the economically more active, commercialized, and monetized rice-dominant regions of China (Bray, 1986; Huang, 1990). The previously stabilized and normative form of sanctions in this community would likely fail to coerce individuals who had become loggers. In fact, Smith (1961) alludes to this when he says "economic sanctions are [no] longer particularly threatening" in the Japanese rural communities he studies.

The presence of a **RD** mutant dramatically shifts the payoffs of all other **S** agents in its group. The defecting mutant must now be punished every round in order to reduce its relative fitness, regardless of punishments' lack of efficacy in

coercing cooperation: In order to remain stable, **S** must punish and more so must not only defectors but also those who fail to punish because they observe that punishment is ineffective, those who do not punish those who do not punish, and so forth, *ad infinitum*. If such moralistic punishment does not occur, cooperation may ultimately collapse (Boyd and Richerson, 1992; Hirshleifer and Rasmusen, 1989).

Now, a focal **S** receives a payoff of:

$$V(\mathbf{S}|1 \mathbf{RD}) = \frac{1}{1-\omega} \left[\frac{b}{n}(n-1) - c - h_s + \beta(n-1) \right] \quad (13)$$

where h_s denotes the cost **S** pays to punish the mutant **RD**. **S**s in this group are doomed to a lifetime of ineffectively punishing a non-contrite type, decreasing the efficiency at which cooperation is stabilized, negatively impacting fitness and subjectively experienced welfare.

However, **O**, as hinted by previous results, does not suffer from this efficiency concern. Should an **RD** mutant emerge in a group composed entirely of **O**s, the defector will simply be removed from the group (Appendix A.4). Consider therefore a strategy, **SO**, that sanctions defectors for a single round and then ostracizes any defector who does not cooperate after the first round. It pays three costs: the direct cost to punishing another agent, h_{SO} ; the direct cost of ostracizing a defector that failed to respond to punishment, h_O ; and the indirect cost of agents having been removed from the group, because of the aforementioned ostracism, $\Gamma(n-s) < \Gamma(n)$ where $s \in \{1, 2, \dots, n-1\}$ denotes the number of **RD**s in the group. Such a strategy might successfully invade a **S** population because it avoids having to punish **RD** mutants repeatedly.

In Appendix B.1 we derive the conditions under which a mutant **SO** can invade a population composed of **S** when **RD** mutants have some ϵ probability of mutating into the population. Assuming a linear group externality function,

SO can invade so long as:

$$h_{SO} + h_O + \frac{\omega\beta}{1-\omega} < \frac{h_S}{1-\omega} \quad (14)$$

This criterion indicates that although **SO** avoids unnecessarily punishing the **RD** mutant, she gets no free lunch. Any such gain is paid for by the cost of having reduced group size by 1 after the defector is ejected. If $\beta \gtrsim h_S$, then we have no reason to believe that **SO** can out compete **S**. However, should group-externality functions be concave, as in Equation 2, we might expect the effect of reducing group-size by 1 to be small. If removing a single agent from the group does little to decrease group-externality payoffs, then the harm to ostracizing strategies of kicking out a mutant defector would be limited. The degree of concavity, ϕ , permitting **SO** invasion is given by:

$$\phi < \frac{\log(1 - \frac{\omega h_S}{\gamma - \alpha})}{\log(1 - \frac{1}{n-1})} \quad (15)$$

This expression is unfortunately complicated and can be made clearer when we adopt the approximation $\log(1+x) \approx x$, under the reasonable assumption that $\gamma - \alpha \gg \omega h_s$ and $n - 1 \gg 1$, in which case the criterion takes the form:

$$\phi < \frac{\omega(n-1)h_S}{\gamma - \alpha} \quad (16)$$

The maximum value that ϕ can take is increased when equilibrium group size or the cost of sanctions that **S** adopts is large relative to the harshness of the ecology (the denominator).

Figure 3 plots the original criterion permitting a **SO** invasion, plotting the maximum value ϕ can take that as a function of equilibrium group-size for four various ecologies, $\gamma - \alpha \in \{4, 8, 12, 20\}$. It demonstrates that even in the harshest

ecologies, removing a single individual from a group has essentially no impact on the group-externality payoff of **SO**, permitting its invasion:

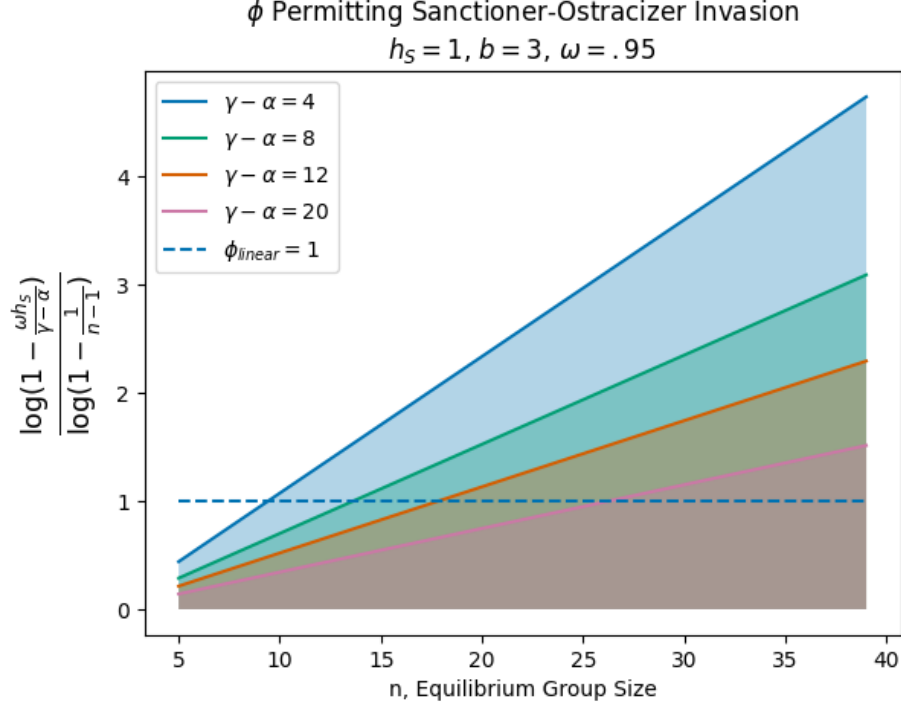


Figure 3: When groups are large and group-externality functions concave, **SO** can generally invade a **S** population because ostracizing a mutant defector does little to change group-externality payoffs. The solid lines plot the maximum ϕ value permitting **SO** invasion and the shaded areas represent the set of all ϕ permitting invasion. The dotted line denotes the maximum value that ϕ can take, which is also when group-externality functions are linear. For reasonable group sizes, small degrees of concavity permit invasion; however, when groups are restricted to smaller sizes but ecologies are harsh, i.e. $n = 15$ and $\gamma - \alpha = 20$, ϕ must be smaller.

3.3.2. Logic of Defection

Up to this point, we have assumed that **S** and **SO** punish in similar ways, i.e. that $h_S \cong h_{SO}$. However, we need not make this assumption and, once ostracism invades a simple sanctioning population, the cost of h_{SO} will be free to vary. Note that **SO** dominates **S** whenever **RD** mutants exist with probability ϵ . Before this point, we should assume that **O** must punish in an identical fashion

to **S** in order to avoid punishment herself. Punishment is by and large a norm-structured behavior and a punishing agent must behave appropriately in the eyes of whatever dominant punishing coalition exists. Below we demonstrate that mutant defectors will reason differently in **SO** groups than in **S** ones. These distinctions will show that the imposed cost of **SO**'s first-round sanction, k_{SO} , is irrelevant in determining a defector's path of play and ultimately, coercing cooperation. The punishment costs that defectors face in **S** groups, k_S , however, largely determines whether defectors will be contrite, and ultimately cooperate, or recalcitrant, and impose large costs on the community.

Suppose that the population agents are drawn from is now modified into a meta-population such that an extremely large sub-population or compartment exists. With probability ϵ , a single member of each group is sampled from this compartment. Individuals sampled from this compartment are forced to adopt one of two strategies: **RD** or **CD**. Though we need not assume any rational-choice procedure, such a compartment may represent the sporadic arising of individuals who, for idiosyncratic reasons, seek to "test the system". Such individuals, when they arise with probability ϵ , will always defect on the first round before considering their future courses of action from the second-round forward, deciding whether to continue defecting or to begin cooperating. Within this compartment, returning to cooperation (**CD**) provides higher fitness than recalcitrant-defection (**RD**) so long as (proof in Appendix B.2):

$$c - \frac{b}{n} < \frac{\omega(b - c) + \gamma - \alpha}{1 - \omega} \quad (17)$$

The cost of punishment that **SO** imposes on the first round, k_{SO} , does not enter into the criterion because the ponderous-defector effectively compares its payoffs from the second round forwards, differing in whether it continues to defect or begins to cooperate. In other words, **CD** is behaviorally identical

to, and could be formally represented by, a cooperating strategy. However, **SO** only punishes an initial defection before ostracizing any repeat defectors and correspondingly, the cost of the initial punishment is irrelevant in determining the ponderous-defectors' course of action. Both defecting strategies in the compartment experience this first-round punishment and it correspondingly does not contribute to fitness-differences. So long as the benefit of the fully stabilized public good to the individual and the benefit of group-life exceeds the single round net-cost of cooperation that the mutant free-rides on, then contrite-defection is always fitness-maximizing relative to recalcitrant defection. Compare this with the same criterion for a defector deciding its path of play in a population defined by **Ss**:

$$c - \frac{b}{n} < k_S(n - 1) \quad (18)$$

Now, the cost of the punishment imposed, k_S , does contribute to determining what path of play a ponderous "testing-defector" will adopt. Correspondingly, the punishment technology that **Ss** adopt must be calibrated to the local community and environment such that punishment convinces defectors to cooperate. This calibration procedure however is not a one-time collective decision process. Whenever environmental change or cultural evolution endogenously produces sufficient social differentiation that punishment technologies no longer coerce cooperation for some subset of the community, punishment must again be recalibrated such that the above criterion again holds. Should it not defection will recalcitrantly occur.

However, the logic of defection in the case of ostracism is distinct. Because the punishment term does not contribute to avoiding recalcitrant defection, it can take any form. Additionally, recalcitrant agents that continue to defect are ostracized from the community *and can no longer free-ride on the public*

good; correspondingly, the benefit associated with cooperation enters into the decision-making process. More so, if we consider a long living organism then $\omega \approx 1$ and Equation 17 becomes:

$$c - b < \gamma - \alpha \quad (19)$$

However, again, because $|\gamma - \alpha| \gg |b|$, b need not take specific values to stabilize cooperation. Even if social differentiation has occurred such that our ponderous defector experiences larger costs of cooperation than (group-level and not marginal) benefits, a $b = 0$, or even a is $b < 0$, the criterion will likely be satisfied.

4. Discussion

Our results demonstrate that ostracism's unique function is precisely what prevents its evolution as an alternative to targeted sanctions. When rare, ostracizing strategies face two main difficulties. First, unlike a simple sanctioning strategy, **O** is not a successful niche constructor. When rare, its presence does not increase the fitness of contrite defectors relative to recalcitrant ones (Boyd and Richerson, 1992) and thus ostracizing strategies cannot establish the conditions permitting their own proliferation, like targeted sanctioning strategies can. The presence of recalcitrant strategies poses a significantly greater problem for the evolution of cooperation as compared to contrite ones, who begin to cooperate if given sufficient cause. Second, ostracism displays strong frequency-dependence. When it is rare, simple non-sanctioning ostracizing strategies simply self-ostracize. For an obligate social organism, the intrinsic benefits associated with living in a group will far exceed the benefit associated with any public good behavior that **O** seeks to stabilize. When rare, ostracism is a strongly deleterious behavior and ostracizing strategies have little to no invasion potential.

This result does not change not only if we permit strategies to assort, but additionally consider the fact that group-externality functions are likely concave.

When frequent, ostracism shows both advantages and disadvantages. Ostracism is a very stable strategy and is able to effectively isolate itself from recalcitrant defectors, who cannot be "convinced" to cooperate. Such recalcitrant defectors might be the endogenous result of cultural evolutionary processes that produce heterogeneity in how community-members are impacted by established norms, extant moralistic forms of punishment, and the set of possible alternative norms. Their presence, should execution not be possible, imposes significant welfare costs on sanctioning strategies, which must punish (moralistically) to maintain their fitness-advantage relative to defectors (Boyd and Richerson, 1992).

However, while ostracism's strong response to defection isolates it from recalcitrant-defectors, as previously discussed, it also "leaves money on the table" and forgoes possible cooperation with contrite-defectors. This is because simple ostracizing strategies never seek to coerce cooperation from contrite-defectors who *will* cooperate if given sufficient cause. Naive ostracism is simply inefficient. Of course, one could imagine a graduated form of ostracism whereby ostracizers ostracize individuals from participation in a subset of mutually-beneficial social activities. This, effectively, is our **SO** strategy, which, prior to ostracism, imposes a cost on defectors and then ostracizes any repeat-defectors. Such a strategy combines the benefits of sanctioning with ostracism and, when recalcitrant defectors arise spontaneously, can invade sanctioning populations. Correspondingly, our model demonstrates that ostracism should be considered a specific and conditional form of sanctioning rather than an alternative to sanctioning-strategies.

Once **SO** is common though, interestingly, the reasoning that mutant de-

factors considering their future paths of play will go through changes. In **SO** populations, all that matters is the net-cost of the stabilized public good as compared to the group-externality cost of ostracism (Equation 17). The pre-ostracism punishment is completely irrelevant. This is not true in **S** populations where the cost of sanctions relative to the net-marginal-cost of adopting the public-good behavior determines a defector's path of play (Equation 18).

This result helps to explain the presence of low-cost sanctions and verbal reprimands or signals by cooperators in the ethnographic literature, though the latter case requires a signaling model to fully assess. In groups that use sanctions prior to ostracism, a "one-sized-fits-all" action must be taken by cooperators—reprimand then simply do not interact with defectors, but the reprimand is irrelevant in coercing cooperation: A defector that is deciding whether to cooperate after they have been reprimanded or to continue to defect need only compare the cost of being ostracized and losing out on the public good to the net-cost of the public good ($c - b$). However, in groups that merely sanction, punishment of defectors must occur each and every round in order to prevent a mutant defector from being recalcitrant.

The above distinction suggests another benefit to ostracism. Ostracizing groups need not pay the repeated costs of calibrating their punishment technology as social differentiation and environmental change occurs. Such collective decision processes may be expensive or even impossible in groups that do not possess sufficiently dense communication networks such that information concerning changes in punishment technologies can be spread with high-fidelity. Information loss may occur either because of environmental restrictions on social networks, such as actual physical distance and low rates of interaction, or because of social constraints, such as when communities are fractionalized by factional conflict or social interaction is largely internal to a subset of the

community.

Additionally, the above line of thought suggests that norms stabilized by ostracism may be slower to change than norms stabilized by means of punishment. When norms are stabilized by sanctions, should all individuals come to recognize the inefficiency of punishment, it and the corresponding norm may simply be abandoned. However, the criterion in Equation 18 will almost always be satisfied, so long as individuals receive negative payoffs from exiting groups. More so, recalcitrant-defectors *do not impose costs on community members when norms are stabilized by ostracism*, however they do impose large costs on community-members when norms are stabilized by sanctions. This distinction means that when a community stabilizes norms by ostracism, members to that community will not be forced to internalize, to *any degree*, how defectors experience a norm. For instance, imagine that every generation, each community member comes to be "hobbled" with some small probability and that hobbled individuals experience a significantly larger cost when contributing to a stabilized public good than the rest of the members to the community. Should that individual be ostracized, the community can simply ignore the existence of "hobbled" individuals. Assuming nonlinear group externality functions, their absence imposes only marginal costs on the remaining community members. Now, consider a community whereby norms are stabilized by sanctions. There, individuals must take costly-actions, each and every round, to punish "hobbled" individuals. Such costs may be large over time and encourage the non-hobbled community members to consider adopting changes such that the hobbled members experience lower costs to cooperation such that community-members need no longer adopt costs to punish them.

Relatedly, norms stabilized by ostracism may change in a more punctuated manner than norms stabilized by sanctions. Consider the case of the Euro-

pean colonization of the Americas. In a relatively condensed period of time, individuals' outside option with respect to their group-externality payoff suddenly increased relative to what it had been, releasing the $\gamma - \alpha$ constraint. For at least some subset of individuals, ostracism no longer meant that individuals were forced into sub-optimal conditions, but could pursue potentially elevated payoffs elsewhere. Correspondingly, individuals self-ostracized, potentially lowering community-members who remained payoffs, both by restricting their ability to allocate public goods and decreasing group size, lowering group-externality payoffs. Of course, this assumes that communities were at optimal group size, which rarely holds. However, an interesting historical psychological (Muthukrishna et al., 2021) question would be to investigate the effects of migration on norms among community-members who did not emigrate. Was there more emigration from and less norm stability in areas where colonization provided individuals with relatively higher group-externality payoffs? Diachronically, does normative change occur at a different rate in communities that saw more emigration compared to less?

Finally, it is not exactly clear how ostracism relates to higher-order punishment. Should individuals who do not ostracize themselves be ostracized? Or should they face some alternative, perhaps targeted sanction? In light of our model and the argument that ostracism and sanctioning serve distinct functions, the answer to this question is not immediately obvious. Further theoretical work should explore this issue. Similarly, though we have argued that the initial punishment conducted by ostracizing strategies that initially sanction is irrelevant in coercing cooperation in equilibrium, the full dynamics of a signaling model of ostracism is required to concretely make this claim.

Appendix A. Ostracizer

Appendix A.1. *Ostracizer and Recalcitrant-Defector Payoff Functions*

O attempts to cooperate on the first round. If any other agent defects, it pays a private cost, h , to drive them out of the group. Assume, additionally, that the public good cannot be produced by a lone-agent, i.e. that if **O** is the lone ostracizing agent in the group that once it abandons the group it cannot cooperate. Payoffs, assuming a linear group-externality term (Equation 1), are given for each strategy below, where m denotes the number of other **O** in a group:

$$V(\mathbf{O}|m) = \frac{b}{n}(m+1) - c + \alpha + \beta(n-1) - h(n-m-1) + \frac{\omega}{1-\omega} \left[\frac{b}{n}(m+1) - c + \alpha + \beta m \right] \quad (\text{A.1})$$

RD initially free-rides on **O** cooperation before being ostracized in the second round. It then lives in a group of reduced size with no access to the public good.

$$V(\mathbf{RD}|m) = \frac{b}{n}m + \alpha + \beta(n-1) + \frac{\omega}{1-\omega} [\alpha + \beta(n-m-1)] \quad (\text{A.2})$$

Appendix A.2. *Ostracizer and Recalcitrant-Defector Fitness Functions*

Fitness functions are constructed in the standard fashion. Payoffs to a strategy for a given group-composition groups are summed across the probability of said group being formed A.3. The fitness of strategy i in a group of size n with m **O**s and a baseline fitness of w_0 is defined as:

$$W_i = w_0 + \sum_{m=0}^{n-1} V_i Pr(m|i) \quad (\text{A.3})$$

where V_i is the payoff of the i^{th} type ($i \in \{O, RD\}$) and $Pr(m|i)$ is the probability of a group with m individuals of type i being formed. Following previous

models of assortment (Boyd and Richerson, 1988, 1992), we define the conditional probability of an individual in a group having strategy S_i , given that the focal strategy is S_i , as:

$$Pr(S_i|S_i) = r + (1 - r)p_i \quad (\text{A.4})$$

where p_i is the frequency of S_i . Similarly, the probability of an alternative strategy, S_j , being chosen is given by:

$$Pr(S_j|S_i) = (1 - r)p_j \quad (\text{A.5})$$

Groups are drawn from an infinitely sized population. The frequency of **O**s in the population is p leaving $1 - p$ as the frequency of **RD**s. The probability of strategy i finding itself in a group of m other individuals sharing its strategy is:

$$Pr(m|i) = \binom{n-1}{m} (r + (1 - r)p)^m [(1 - r)(1 - p)]^{n-m-1} \quad (\text{A.6})$$

By taking expectations across the payoff functions described in section Appendix A.1, We construct the fitness functions for each strategy:

$$\begin{aligned} W(\mathbf{O}) = & w_0 + \frac{b}{n} [(n-1)(r + (1 - r)p) + 1] - c + \\ & \alpha + \beta(n-1) - h(n-1)(1 - r)(1 - p) + \\ & \frac{\omega}{1 - \omega} \left[\alpha + \beta(n-1)(r + (1 - r)p) + \frac{b}{n} [(n-1)(r + (1 - r)p) + 1] - c \right] \end{aligned} \quad (\text{A.7})$$

$$\begin{aligned} W(\mathbf{RD}) = & w_0 + \frac{b}{n} (n-1)(1 - r)p + \alpha + \beta(n-1) + \\ & \frac{\omega}{1 - \omega} (\alpha + \beta(n-1) [r + (1 - r)(1 - p)]) \end{aligned} \quad (\text{A.8})$$

Assuming reproduction is proportional to payoffs then \mathbf{O} increases in fitness so long as:

$$\begin{aligned} & \frac{\frac{b}{n}(r(n-1)+1)-c}{1-\omega} - h(n-1)(1-r)(1-p) + \\ & \frac{\omega}{1-\omega}(n-1)(1-r) \left[\beta(2p-1) + \frac{b}{n}p \right] > 0 \end{aligned} \quad (\text{A.9})$$

Rearranging this criterion defines our invasion barrier:

$$p > \frac{h(n-1)(1-r) + \frac{1}{1-\omega} \left[c - \frac{b}{n}r(n-1) + \omega\beta(n-1)(1-r) \right]}{h(n-1)(1-r) + \frac{\omega}{1-\omega}(n-1)(1-r) \left[2\beta + \frac{b}{n} \right]} \quad (\text{A.10})$$

If we assume that $\omega \approx 1$ then the right-hand-side is well approximated by:

$$p > \frac{c - \frac{b}{n}(r(n-1)+1) + \omega\beta(n-1)(1-r)}{\omega(n-1)(1-r)(2\beta + \frac{b}{n})} \quad (\text{A.11})$$

Appendix A.3. **Ostracizer** Invasion of **Recalcitrant-Defector** Population

Appendix A.3.1. Linear Gamma With Assortment

When \mathbf{O} is rare $p = 0$ and it will only encounter $n-1$ \mathbf{R} s whereas the average resident \mathbf{RD} will only encounter itself. Setting p in Equation A.9 to zero, we are given the criterion in the main text, Equation 7.

Appendix A.3.2. Nonlinear Gamma With Assortment

We now construct a toy model of invasion to examine how concave group-externality functions interact with assortment or prestige transmission. Assume now that the group-externality term is given by Equation 2. This means that α is what an agent receives when they are alone in a group and γ in a group of equilibrium size n . Assume additionally that the mutant \mathbf{O} is able to convince each of the $n-1$ individuals in its group to adopt its own strategy with probability r . It does this after observing the outcome of the public good round but before ostracizing any agents. Assuming an independent rate of success, i.e. that there is no self-reinforcing property to success or failure, then the mutant

will successfully convince $r(n-1)$ group-members to become **O**s. The focal mutant **O**'s payoff is now given by:

$$V(\mathbf{O}|m=0) = \frac{b}{n} - c + \gamma - h(n-1)(1-r) + \frac{\omega}{1-\omega} \left[\frac{b}{n} [(n-1)r+1] - c + \alpha + (\gamma - \alpha) \left(\frac{(n-1)r}{n-1} \right)^\phi \right] \quad (\text{A.12})$$

And the average **RD** experiences only the full group-externality term:

$$V(\mathbf{RD}|m=0) = \frac{\gamma}{1-\omega} \quad (\text{A.13})$$

$V(\mathbf{O}|m=0) > V(\mathbf{RD}|m=0)$ when:

$$\begin{aligned} & -h(n-1)(1-r) + \frac{\omega}{1-\omega} \left[\frac{b}{n}(n-1)r + \alpha + (\gamma - \alpha)r^\phi \right] \\ & > \\ & \frac{c - \frac{b}{n} + \omega\gamma}{1-\omega} \end{aligned} \quad (\text{A.14})$$

This equation cannot be solved analytically. However, humans are a long-lived organism and we should expect the $\frac{1}{1-\omega}$ terms to dominate assuming $\omega \approx 1$, reducing it to a slightly more manageable form:

$$\begin{aligned} & \frac{b}{n}(n-1)r + (\gamma - \alpha)r^\phi \\ & > \\ & \frac{1}{\omega} \left(c - \frac{b}{n} \right) + \gamma - \alpha \end{aligned} \quad (\text{A.15})$$

Appendix A.4. ***Ostracizer** Stability to **Recalcitrant-Defector** Invasion*

O will be stable in the face of an invading **RD** mutant when $V(\mathbf{O}|m = n-1) > V(\mathbf{RD}|m = n-1)$ where m again denotes the number of other **O**s in the group. Using the payoff functions from the main text, we can rewrite this

expression, using the nonlinear group-externality function (Equation 2) as:

$$\frac{b-c+\gamma}{1-\omega} > \frac{b(n-1)}{n} + \gamma + \frac{\omega}{1-\omega}\alpha \quad (\text{A.16})$$

On the left hand side, **O** encounters only itself and thus experiences both the full public good minus the individual contribution cost, and the full group-externality term. On the right hand side, **RD** is able to free-ride on the public good for a single round, but is then ostracized, losing access both to the public good and the group externality term for the remainder of its lifetime. We can rearrange this expression into a slightly more intuitive form:

$$\frac{b-c}{1-\omega} > \frac{b(n-1)}{n} + \frac{\omega}{1-\omega}(\alpha - \gamma) \quad (\text{A.17})$$

Now it is obvious that the right hand side is negative. The term $\alpha - \gamma$ is the decrease in **RD**'s upon being ostracized. This negative term is experienced by **RD** for the remainder of its life, $\frac{\omega}{1-\omega}$ and is only resisted by the positive single round of free-riding on the public good, $\frac{b(n-1)}{n}$. If we only consider the $\frac{1}{1-\omega}$ terms under that assumption that $\omega \approx 1$ and n is large, the criterion can be further reduced to:

$$\omega b - c > \alpha - \gamma \quad (\text{A.18})$$

The benefit associated with the public good must exceed the mutant's loss of group-externality payoff. Correspondingly, this criterion must be true as the left-hand-side is positive and the right-hand-side is negative.

Appendix A.5. Ostracizer Stability to Contrite-Defector Invasion

If we examine the stability of **O** with respect to a contrite type of defector, that upon experience the cost of being ostracized, i.e. the loss of the group externality payoff, pays a cost to re-enter the community (akin to a signal of its

contribution) whereupon it begins contributing to the public good again, then its payoff is given by:

$$V(\mathbf{CD}|m = n - 1) = b\frac{n-1}{n} + \gamma + \omega(\alpha - c_D) + \frac{\omega^2}{1-\omega}(b - c + \gamma) \quad (\text{A.19})$$

O's payoff is the standard lifetime access to the public good and full group externality term: $\frac{b-c+\gamma}{1-\omega}$ as given above in Appendix A.4. **O**'s fitness is higher so long as:

$$\omega(b - c + \gamma - \alpha + c_D) > c - \frac{b}{n} \quad (\text{A.20})$$

Appendix B. Sanctioner-Ostracizer

Appendix B.1. *Sanctioner-Ostracizer Invasion of Sanctioner Population*

Appendix B.1.1. *Linear Group-Externality*

Assume that **RD** mutants have some probability of arising in the population, due to errors or some other mechanism. In groups where no **RD** mutant arises, a **SO** mutant will have an identical payoff to **S** because they both cooperate on all rounds. Assuming a linear group externality function, i.e. Equation 1, then in groups where a **RD** mutant arises, **S**'s payoff, as given in the main text in Equation 13, is denoted by:

$$V(\mathbf{S}|1 \mathbf{RD}) = \frac{1}{1-\omega} \left[\frac{b}{n}(n-1) - c - h_s + \alpha + \beta(n-1) \right] \quad (\text{B.1})$$

SO's payoff in such groups is given by:

$$\begin{aligned} V(\mathbf{SO}|1 \mathbf{RD}) = & b\frac{n-1}{n} - c - h_{SO} + \alpha + \beta(n-1) + \\ & \omega \left[b\frac{n-1}{n} - c - h_O + \alpha + \beta(n-2) \right] + \\ & \frac{\omega^2}{1-\omega} \left[b\frac{n-1}{n} - c + \alpha + \beta(n-2) \right] \end{aligned} \quad (\text{B.2})$$

To define this equation We also assume that on the second round, **O** is able to adopt the cost of ostracism herself and successfully eject the defector and that the community does not punish her for this action. A **SO** mutant can invade an **S** population so long as $V(\mathbf{S}|\mathbf{1RD}) < V(\mathbf{SO}|\mathbf{1RD})$:

$$\begin{aligned} & \frac{1}{1-\omega} \left[b \frac{n-1}{n} - c - h_S + \beta(n-1) \right] \\ & < \\ & b \frac{n-1}{n} - c - h_{SO} + \beta(n-1) + \omega \left[b \frac{n-1}{n} - c - h_O + \beta(n-2) \right] + \\ & \frac{\omega^2}{1-\omega} \left[b \frac{n-1}{n} - c + \beta(n-2) \right] \end{aligned} \quad (\text{B.3})$$

which reduces to:

$$h_{SO} + h_O + \frac{\omega\beta}{1-\omega} < \frac{h_S}{1-\omega} \quad (\text{B.4})$$

The right-hand-side denotes the cost **S** adopts in order to punish the **RD** mutant for the rest of its life. The left-hand-side denotes, from left-to-right, the cost **SO** adopts to punishes the defecting mutant on the first round, the cost to ostracizes the mutant on the second round, and then the life-long experience of a reduced group-size ($\frac{\omega\beta}{1-\omega}$).

So long as the above criterion holds, **SO** will completely replace **S**. Assume m is the number of **SO** in a group, $n - m - 1$ denotes the number of **S**, and there is 1 **RD** mutant. **SO** and **S** payoffs are identical in the first and second round, assuming $h_{SO} = h_S = h_O$. From the third round forwards, payoffs for each strategy in groups with 1 **RD** are:

$$\begin{aligned} V(\mathbf{SO} | m = 0) &= \frac{\omega^2}{1-\omega} \left[\frac{b}{n}(n-1) - c - h_s + \beta(n-1) \right] \\ V(\mathbf{SO} | m > 0) &= V(\mathbf{S}) = \frac{\omega^2}{1-\omega} \left[\frac{b}{n}(n-1) - c \quad + \beta(n-2) \right] \end{aligned} \quad (\text{B.5})$$

Appendix B.1.2. Nonlinear Group-Externality

When the group-externality term is nonlinear, Equation 2 holds: $\Gamma(x) = \alpha + (\gamma - \alpha)\frac{x-1}{n-1}^\phi$ where n is the equilibrium group size and x is the current number of individuals in the group. Being a member of a group at equilibrium earns an agent γ and once **SO** removes the recalcitrant defecting mutant, her group-externality term becomes $\alpha + (\gamma - \alpha)\frac{n-2}{n-1}^\phi$. The criterion then becomes:

$$\frac{-h_S + \omega\gamma}{1 - \omega} < -h_{SO} + \omega \left[-h_O + \frac{\alpha + (\gamma - \alpha)(1 - \frac{1}{n-1})^\phi}{1 - \omega} \right] \quad (\text{B.6})$$

Assume that $h_{SO} \approx h_S$. This will be the case if punishment is normative and moralistic, i.e. that **SO** must punish in an identical form as the resident **S** in order to herself avoid punishment. Additionally assume that the cost of ostracism, h_O also is of approximate magnitude as h_S . Then the criterion can be rewritten as:

$$-\omega h_S + \gamma < \alpha + (\gamma - \alpha)(1 - \frac{1}{n-1})^\phi \quad (\text{B.7})$$

which can be rewritten as:

$$\phi < \frac{\log(1 - \frac{\omega h_S}{\gamma - \alpha})}{\log(1 - \frac{1}{n-1})} \quad (\text{B.8})$$

If we additionally assume that groups are large and important (that $\gamma - \alpha$ is large) then we can approximate $\log(1 + x) \approx x$ and the criterion becomes:

$$\phi < \frac{\omega(n-1)h_S}{\gamma - \alpha} \quad (\text{B.9})$$

Appendix B.2. Logic of Defection

Should the mutant in a group of $n - 1$ **SO** choose to recalcitrantly defect, it will be ostracized on the second-round and receive a payoff of:

$$V(\mathbf{RD}|n-1 \mathbf{SO}) = b\frac{n-1}{n} - k_{SO}(n-1) + \gamma + \omega(b\frac{n-1}{n} + \alpha) + \frac{\omega^2}{1-\omega}\alpha \quad (\text{B.10})$$

Should it choose to contritely defect and respond to punishment, it will receive a payoff of:

$$V(\mathbf{CD}|n-1 \mathbf{SO}) = b\frac{n-1}{n} - k_{SO}(n-1) + \gamma + \omega(b-c+\gamma) + \frac{\omega^2}{1-\omega}(b-c+\gamma) \quad (\text{B.11})$$

CD (and cooperation) is the best-response so long as:

$$c - \frac{b}{n} < \frac{\omega(b-c) + \gamma - \alpha}{1-\omega} \quad (\text{B.12})$$

When the mutant is in a group of $n - 1$ **Ss**, **RD**'s payoff is:

$$V(RD|n-1 S) = \frac{b\frac{n-1}{n} - k_S(n-1) + \gamma}{1-\omega} \quad (\text{B.13})$$

Should it choose to contritely defect and respond to punishment, it will receive a payoff of:

$$V(\mathbf{CD}|n-1 \mathbf{S}) = b\frac{n-1}{n} - k_S(n-1) + \gamma + \frac{\omega}{1-\omega}(b-c+\gamma) \quad (\text{B.14})$$

CD receives is the best-response so long as Boyd and Richerson's familiar criterion hold:

$$c - \frac{b}{n} < k_S(n-1) \quad (\text{B.15})$$

References

- J. Briggs, *Never in Anger: Portrait of an Eskimo Family*, Harvard University Press, Cambridge, MA, 1971.
- R. J. Smith, The Japanese rural community: Norms, sanctions, and ostracism, *American Anthropologist* 63 (1961) 522–533. doi:10.1525/aa.1961.63.3.02a00050.
- E. A. Hoebel, Associations and the state in the plains, *American Anthropologist* 38 (1936) 433–438. doi:10.1525/aa.1936.38.3.02a00060.
- I. Amadiume, *Male Daughters, Female Husbands: Gender and Sex in an African Society*, Zed Books, London, 2015.
- M. Olson, *The Logic of Collective Action: Public Goods and the Theory of Groups*, Harvard University Press, Cambridge, 1971.
- P. A. Samuelson, The pure theory of public expenditure, *The Review of Economics and Statistics* 36 (1954) 387–389. doi:10.2307/1925895. arXiv:1925895.
- M. Taylor, *The Possibility of Cooperation*, Cambridge University Press, Cambridge, UK, 1987.
- R. Boyd, H. Gintis, S. Bowles, Coordinated punishment of defectors sustains cooperation and can proliferate when rare, *Science* 328 (2010) 617–620. doi:10.1126/science.1183665.
- R. Boyd, P. J. Richerson, Punishment allows the evolution of cooperation (or anything else) in sizable groups, *Ethology and Sociobiology* 13 (1992) 171–195. doi:10.1016/0162-3095(92)90032-Y.

- A. Chaudhuri, Sustaining cooperation in laboratory public goods experiments: A selective survey of the literature, *Experimental Economics* 14 (2011) 47–83. doi:10.1007/s10683-010-9257-1.
- E. Fehr, U. Fischbacher, Third-party punishment and social norms, *Evolution and Human Behavior* 25 (2004) 63–87. doi:10.1016/S1090-5138(04)00005-4.
- E. Fehr, S. Gächter, Cooperation and punishment in public goods experiments, *American Economic Review* 90 (2000) 980–994.
- B. Herrmann, C. Thoni, S. Gächter, Antisocial punishment across societies, *Science* (New York, N.Y.) 319 (2008) 1362–1367. doi:10.1126/science.1153808. arXiv:1101.2204.
- S. Mathew, R. Boyd, Punishment sustains large-scale cooperation in prestate warfare, *Proceedings of the National Academy of Sciences* 108 (2011) 11375–11380. doi:10.1073/pnas.1105604108. arXiv:https://www.pnas.org/content/108/28/11375.full.pdf.
- S. Mathew, R. Boyd, The cost of cowardice: Punitive sentiments towards free riders in Turkana raids, *Evolution and Human Behavior* 35 (2014) 58–64. doi:10.1016/j.evolhumbehav.2013.10.001.
- J. Henrich, R. McElreath, A. Barr, J. Ensminger, C. Barrett, A. Bolyanatz, J. C. Cardenas, M. Gurven, E. Gwako, N. Henrich, C. Lesorogol, F. Marlowe, D. Tracer, J. Ziker, Costly punishment across human societies, *Science* 312 (2006) 1767–1770. doi:10.1126/science.1127333.
- M. Chudek, J. Henrich, Culture-gene coevolution, norm-psychology and the emergence of human prosociality, *Trends in Cognitive Sciences* 15 (2011) 218–226. doi:10.1016/j.tics.2011.03.003.

- J. Henrich, N. Henrich, Fairness without punishment: Behavioral experiments in the Yasawa Island, Fiji, in: J. Ensminger, J. Henrich (Eds.), *Experimenting with Social Norms: Fairness and Punishment in Cross-Cultural Perspective*, Russel Sage Foundation, New York, 2014, pp. 225–258.
- R. Boyd, *A Different Kind of Animal: How Culture Transformed Our Species*, Princeton University Press, Princeton, 2019.
- R. Boyd, P. J. Richerson, Large-scale cooperation in small-scale foraging societies, *Evolutionary Anthropology: Issues, News, and Reviews* 31 (2022) 175–198. doi:10.1002/evan.21944.
- D. Hirshleifer, E. Rasmusen, Cooperation in a repeated prisoners' dilemma with ostracism, *Journal of Economic Behavior & Organization* 12 (1989) 87–106. doi:10.1016/0167-2681(89)90078-4.
- T. Sasaki, S. Uchida, The evolution of cooperation by social exclusion, *Proceedings of the Royal Society B: Biological Sciences* 280 (2013). doi:10.1098/rspb.2012.2498.
- W. A. Foster, J. E. Treherne, Evidence for the dilution effect in the selfish herd from fish predation on a marine insect, *Nature* 293 (1981) 466–467. doi:10.1038/293466a0.
- J. Krause, G. D. Ruxton, *Living in Groups*, Oxford University Press, New York, NY, 2002.
- D. Fudenberg, E. Maskin, The folk theorem in repeated games with discounting or with incomplete information, *Econometrica : journal of the Econometric Society* 54 (1986) 533–554. doi:10.2307/1911307.
- W. D. Hamilton, The genetical evolution of social behaviour. II, *Journal of*

- Theoretical Biology 7 (1964) 17–52. doi:10.1016/0022-5193(64)90039-6. arXiv:1011.1669v3.
- P. S. Park, M. A. Nowak, C. Hilbe, Cooperation in alternating interactions with memory constraints, Nature Communications 13 (2022) 737. doi:10.1038/s41467-022-28336-2.
- J. M. Buchanan, An economic theory of clubs, Economica 32 (1965) 1. doi:10.2307/2552442. arXiv:2552442.
- P. Rivière, Individual and Society in Guiana: A Comparative Study of Amerindian Social Organization, number 51 in Cambridge Studies in Social Anthropology, Cambridge University Press, New York, NY, 1984.
- R. Boyd, P. J. Richerson, J. Henrich, The cultural niche: Why social learning is essential for human adaptation, Proceedings of the National Academy of Sciences 108 (2011) 10918–10925. doi:10.1073/pnas.1100290108.
- C. McClellan, G. Denniston, Environment and culture in the Cordillera, in: J. Helm (Ed.), Handbook of North American Indians, volume 6, Smithsonian Institution, Washington, DC, 1981, pp. 372–386.
- R. Ridington, Technology, world view, and adaptive strategy in a northern hunting society, Canadian Review of Sociology/Revue canadienne de sociologie 19 (1982) 469–481. doi:10.1111/j.1755-618X.1982.tb00875.x.
- R. Ridington, Knowledge, power, and the individual in subarctic hunting societies, American Anthropologist 90 (1988) 98–110. doi:10.1525/aa.1988.90.1.02a00070.
- P. Wiessner, Risk, reciprocity and social influences on !Kung San economics, in: R. B. Lee, E. Leacock (Eds.), Politics and History in Band Societies, Cambridge University Press, Cambridge, 1982, pp. 61–84.

- R. L. Kelly, *The Foraging Spectrum: Diversity in Hunter-Gatherer Lifeways*, Smithsonian Institution Press, Washington, DC, 1995.
- R. Boyd, P. J. Richerson, The evolution of reciprocity in sizable groups, *Journal of Theoretical Biology* 132 (1988) 337–356. doi:10.1016/S0022-5193(88)80219-4.
- H. Gintis, E. A. Smith, S. Bowles, Costly signaling and cooperation, *Journal of Theoretical Biology* 213 (2001) 103–119. doi:10.1006/jtbi.2001.2406.
- K. Panchanathan, R. Boyd, Indirect reciprocity can stabilize cooperation without the second-order free rider problem, *Nature* 432 (2004) 499–502. doi:10.1038/nature02978.
- R. S. Sutton, A. G. Barto, *Reinforcement Learning: An Introduction*, Adaptive Computation and Machine Learning Series, second edition ed., The MIT Press, Cambridge, Massachusetts, 2018.
- A. W. Johnson, T. K. Earle, *The Evolution of Human Societies*, Stanford University Press, Stanford, 1987.
- P. Wiessner, Embers of society: Firelight talk among the Ju/'hoansi Bushmen, *Proceedings of the National Academy of Sciences of the United States of America* 111 (2014) 14027–14035. doi:10.1073/pnas.1404212111.
- R. Boyd, S. Mathew, Arbitration supports reciprocity when there are frequent perception errors, *Nature Human Behaviour* 5 (2021) 596–603. doi:10.1038/s41562-020-01008-1.
- M. A. Nowak, K. Sigmund, Evolution of indirect reciprocity, *Nature* 437 (2005) 1291–niki1298. doi:10.1038/nature04131.

- N. Baumard, Has punishment played a role in the evolution of cooperation? A critical review, *Mind & Society* 9 (2010) 171–192. doi:10.1007/s11299-010-0079-9.
- K. N. Laland, M. J. O'Brien, Cultural niche construction: An introduction, *Biological Theory* 6 (2011) 191–202. doi:10.1007/s13752-012-0026-6.
- F. J. Odling-Smee, K. N. Laland, M. W. Feldman, M. W. Feldman, *Niche Construction: The Neglected Process in Evolution*, Princeton University Press, Princeton, 2003.
- M. Chudek, S. Heller, S. Birch, J. Henrich, Prestige-biased cultural learning: Bystander's differential attention to potential models influences children's learning, *Evolution and Human Behavior* 33 (2012) 46–56. doi:10.1016/j.evolhumbehav.2011.05.005.
- J. Henrich, F. J. Gil-White, The evolution of prestige: Freely conferred deference as a mechanism for enhancing the benefits of cultural transmission, *Evolution and Human Behavior* 22 (2001) 165–196. doi:10.1016/S1090-5138(00)00071-4.
- J. Henrich, M. Chudek, R. Boyd, The big man mechanism: How prestige fosters cooperation and creates prosocial leaders, *Philosophical Transactions of the Royal Society B: Biological Sciences* 370 (2015) 20150013. doi:10.1098/rstb.2015.0013.
- F. Bray, *The Rice Economies: Technology and Development in Asian Societies*, Blackwell, New York, 1986.
- P. C. C. Huang, *The Peasant Family and Rural Development in the Yangtze Delta, 1350-1988.*, Stanford University Press, Stanford, California, 1990.

- N. D. Humphrey, Police and tribal welfare in Plains Indian cultures, *Journal of Criminal Law and Criminology* 33 (1942) 147–161. doi:10.2307/1136421.
- P. Clastres, *Society against the State: Essays in Political Anthropology*, Zone Books : Distributed by the MIT Press, New York; Cambridge, Mass., 2013.
- M. Muthukrishna, J. Henrich, E. Slingerland, Psychology as a historical science, *Annual Review of Psychology* 72 (2021) 717–749. doi:10.1146/annurev-psych-082820-111436.
- R. B. Lee, Eating christmas in the Kalahari, *Natural History* 78 (1969) 14–22, 60–63.
- R. B. Lee, *The !Kung San: Men, Women and Work in a Foraging Society*, Cambridge University Press, Cambridge, 1979.
- R. Boyd, P. J. Richerson, Culture and the evolution of human cooperation, *Philosophical Transactions of the Royal Society B: Biological Sciences* 364 (2009) 3281–3288. doi:10.1098/rstb.2009.0134.
- J. Henrich, Cultural group selection, coevolutionary processes and large-scale cooperation, *Journal of Economic Behavior and Organization* 53 (2004) 3–35. doi:10.1016/S0167-2681(03)00094-5.
- P. Richerson, R. Baldini, A. V. Bell, K. Demps, K. Frost, V. Hillis, S. Mathew, E. K. Newton, N. Naar, L. Newson, C. Ross, P. E. Smaldino, T. M. Waring, M. Zefferman, Cultural group selection plays an essential role in explaining human cooperation: A sketch of the evidence, *Behavioral and Brain Sciences* 39 (2016) 1–71. doi:10.1017/S0140525X1400106X.
- J. Henrich, R. Boyd, Why people punish defectors: Weak conformist transmission can stabilize costly enforcement of norms in cooperative dilemmas, *Journal of Theoretical Biology* 208 (2001) 79–89. doi:10.1006/jtbi.2000.2202.