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Abstract

Strong reciprocity refers to the willingness to sacrifice one's own material self-interest to punish others for opportunistic actions. This propensity provides a decentralized mechanism for the enforcement of social norms, but its extent and persistence poses a theoretical puzzle. Since opportunistic individuals choose optimally to comply with or violate norms based on the likelihood and severity of sanctioning they anticipate, such individuals will always outperform reciprocators within any group. The presence of reciprocators in a group can, however, alter the behavior of opportunists in such a manner as to benefit all members of the group (including reciprocators). We show that under these circumstances, reciprocators can invade a population of opportunists when groups dissolve and are formed anew according to a process of purely random (non-assortative) matching. Furthermore, even when these conditions are not satisfied (so that an opportunistic population is stable) there may exist additional stable population states in which reciprocators are present.

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1 Introduction

Mounting evidence from laboratory experiments and field studies supports the view that strong reciprocity is a widespread and robust feature of human behavior.[1] Such evidence also points to a heterogeneity of motivations in human populations, and the presence of some individuals who appear to be motivated primarily with the pursuit of their own interest. This chapter is concerned with the theoretical question of how such a combination of behavior might have evolved and why it persists.

A central feature of strong reciprocity is the propensity to punish others for opportunistic actions and to reward them for acts of uncommon generosity, where such rewards and punishments are not motivated by the prospect of future gain. The social norms which serve as the benchmark for evaluating behavior may vary from one culture to another but given some such set of broadly shared norms, strong reciprocity provides a decentralized mechanism for their enforcement. The extent and persistence of strong reciprocity poses something of a theoretical puzzle because monitoring and sanctioning activities, while potentially beneficial to the group, place a net material burden on the reciprocator. Since opportunistic individuals choose to comply with or violate norms based on the likelihood and severity of sanctioning they anticipate, such individuals will always outperform reciprocators within any group. Even under complete compliance, reciprocators incur costs that opportunists are able to avoid. One would expect this payoff differential to exert evolutionary pressure on the population composition until reciprocators have been entirely displaced from the group. This suggests that any population composed of immutable groups with no inter-group mobility will not therefore sustain strong reciprocity in the long run.

The situation can be quite different if groups can dissolve and new groups are formed periodically. Strong reciprocity differs from pure altruism in one important respect: the presence of reciprocators in a group can, under very general conditions, alter the behavior of opportunists in such a manner as to benefit all members of the group (including reciprocators).[2] This creates the possibility that in groups containing reciprocators, *all* group members including reciprocators obtain greater payoffs than are obtained in homogeneous groups of self-regarding individuals. We argue below that under these circumstances, reciprocators can invade a population of opportunists when groups dissolve and are formed anew according to a process of purely random (non-assortative) matching. Furthermore, we show that even when these conditions are not satisfied (so that an opportunistic population is stable) there may exist additional stable population states in which reciprocators are present.

The conditions under which strong reciprocity can survive and spread in evolutionary competition with opportunism are explored below within the context of a common pool resource environment. Such environments consist of economically valuable resources to which multiple unrelated users have access. Common pool resources have been the dominant form of property through all of human prehistory and history until the advent of agriculture, and remain economically significant to this day. Coastal fisheries, grazing lands, forests, groundwater basins and irrigation systems are all examples of resources that have traditionally been

[1] See Fehr and Gächter (2000) for a survey of the experimental literature.

[2] Altruism may also have this effect, but does so in a narrower range of environments which exclude those considered in this chapter (Bester and Güth, 1998).

held as common property. A well-known problem that arises in the management of such resources is that when all appropriators independently attempt to maximize their own private gains from resource extraction, the result is a "tragedy of the commons", with overextraction resulting in excessive resource depletion. The tragedy is that all appropriators may end up with smaller net gains that would be obtained under a system of resource management in which restraints on extraction were enforced. In the absence of a government, such enforcement can only come from the appropriators themselves through a decentralized system of monitoring and enforcement.

Strong reciprocity can motivate individuals to undertake such monitoring and enforcement. Field studies of local commons, of which there are several thousand, show that in many cases resource extraction is regulated and restrained by a complex network of social norms held in place by credible threats of sanction.[3] Such systems coerce ordinarily self-interested individuals to behave in ways that reflect pro-social concerns. Overextraction is therefore limited and it is possible for all individuals (including reciprocators) to obtain higher material rewards than the tragedy of the commons would predict. We argue below that this effect helps us understand not only how local commons have been able to survive conditions of extreme scarcity, but also how strong reciprocity itself has been able to survive under evolutionary pressure.

The evolutionary theory of strong reciprocity advanced in Sections 2 and 3 below relies on the ability of reciprocators to make a credible commitment to monitor and sanction norm violators even when it is not in their interest to do so. Alternative evolutionary accounts of strong reciprocity that differ in significant ways from this one have been proposed, and these are reviewed in Section 4. Aside from the power of commitment, two additional themes, which we identify as assortation and parochialism, appear repeatedly in this literature. Our survey of this sometimes technical and specialized literature is neither exhaustive nor mathematical, and should be accessible to a broad range of researchers across disciplinary boundaries.

2 Common Property

The following simple model of common pool resource extraction provides an analytical framework within which the question of preference evolution can be explored.[4] Consider a group of individuals with shared access to a resource which is valuable but costly to appropriate. Each appropriator makes an independent choice regarding her level of resource extraction. The aggregate amount of resource extraction is simply the sum of all individual extraction levels. The total cost of extraction incurred by the group as a whole rises with aggregate extraction in accordance with the following hypothesis: the higher the level of aggregate extraction, the more it costs to extract an *additional* unit of the resource. The share of the total cost of extraction that is paid by any given appropriator is equal to the share of this

[3]For an overview of the evidence from field studies see Bromley (1992) and Ostrom (1990). Laboratory experiments designed to replicate commmon pool resource environments reveal extensive sanctioning behavior that is broadly consistent with the findings from field studies (Ostrom, Walker and Gardner, 1992).

[4]A mathematical analysis of this model with proofs of all claims made in the text may be found in the appendix.

appropriator's extraction in the total extraction by the group. These are standard assumptions in the analysis of common pool resource environments, and imply that an increase in extraction by one appropriator raises the cost of extraction for *all* appropriators.

Figure 1 depicts the manner in which aggregate benefits and costs vary with the level of aggregate extraction. The straight line corresponds to aggregate extraction and the curve to the aggregate costs of extraction. The costs rise gradually at first and then rapidly, so that there is a unique level of aggregate extraction X^* at which *net benefits* are maximized. If each appropriator were to extract an equal share of this amount, the resulting outcome would be optimal from the perspective of the group. However, if all appropriators were to chose this level of extraction, self-interested individuals would prefer to extract more since this would increase their own private payoffs. The fact that this increase would come at the cost of lowering the combined payoff to the group as a whole would not deter a self-interested appropriator. If all appropriators were self-interested, and made independent choices regarding their extraction levels, the resulting level of aggregate extraction would *not* be optimal from the perspective of the group. It is possible to show that in an equilibrium of the game played by a group of self-interested appropriators, each one would choose the same extraction level and that the resulting aggregate extraction X^e would exceed X^* (as shown in Figure 1). The level of extraction under decentralized, self-interested choice is *inefficient*: each member of the group could obtain higher payoffs if all were forced to limit their extraction. This is the tragedy of the commons, in which the optimal pursuit of one's own interest by each appropriator leads to lower payoffs for all than could be realized under a system of "mutual coercion, mutually agreed upon" (Hardin, 1968).

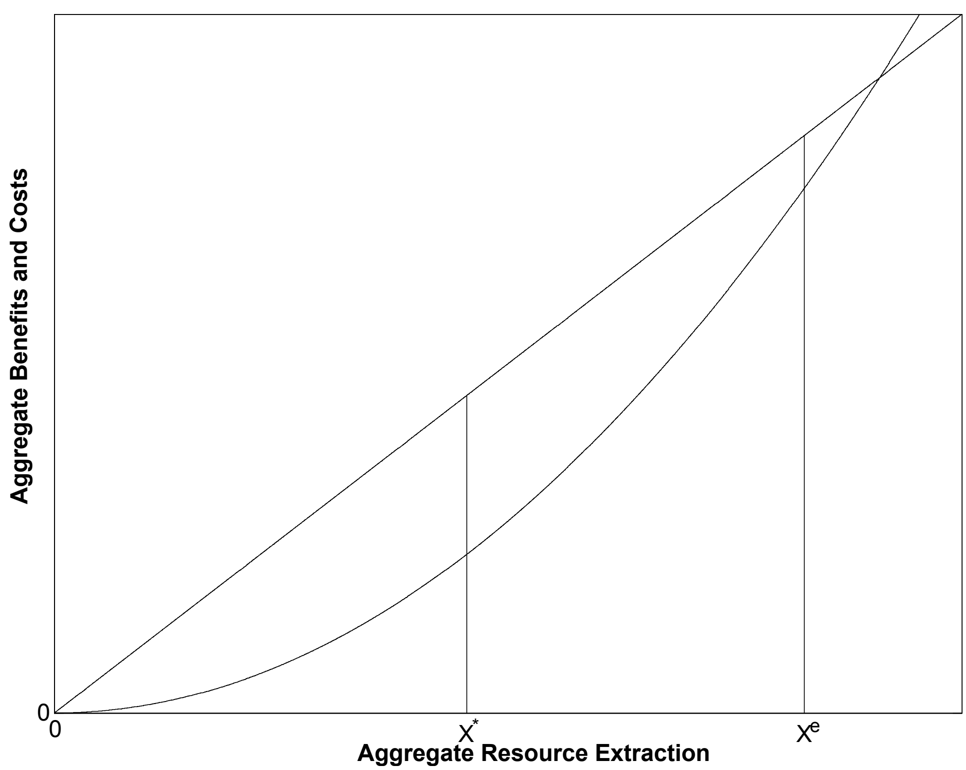

Figure 1. Aggregate Costs and Benefits of Extraction.

Coordinated mutual coercion, however, requires a central authority capable of imposing sanctions on violators. Can groups avoid the tragedy of the commons even in the absence of centralized enforcement? Consider the possibility that individuals may monitor each other (at a cost) and impose decentralized sanctions on those who choose extraction levels that are above some threshold. Specifically, suppose that individuals are of two types, whom we call reciprocators and opportunists. Reciprocators comply with and enforce a norm that prescribes, for each individual, an equal share of the efficient extraction level X^*.[5] Reciprocators monitor others at a cost and are able to detect and sanction all violators. Violators incur a cost as a result of each sanction. Opportunists simply choose extraction levels that maximize their private net benefits from extraction. In doing so, they face a choice between norm compliance, which allows them to escape punishment, and violation, which enables them to choose optimal extraction levels. Which of these two options is more profitable for a given opportunist depends on the population composition of the community and the choices made by other opportunists.

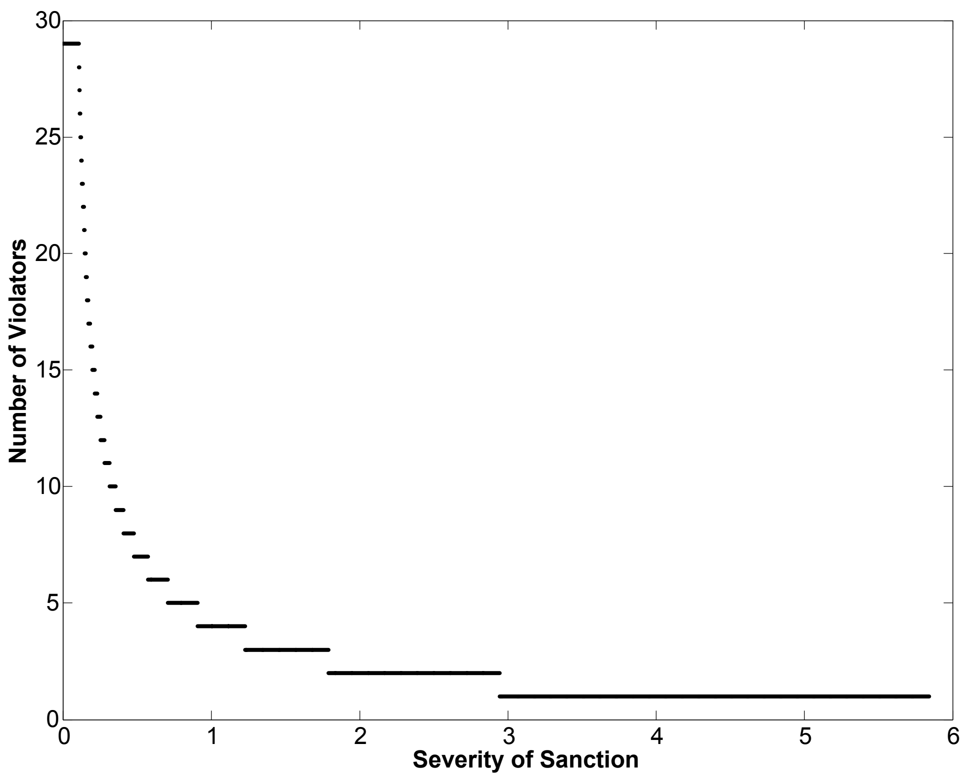

Figure 2. Severity of Sanctions and the Incidence of Compliance.

Consider a group in which both reciprocators and opportunists are present. The opportunists are involved in a strategic interaction in which each must determine her level of extraction. In equilibrium, opportunists fall into one of two groups: those who violate the norm and incur the cost of being punished and those who comply with the norm and escape

[5]It is not essential to the argument that the norm prescribe behavior that is optimal in this sense, only that it result in greater payoffs for the group than would be observed under opportunistic extraction.

punishment. It can be shown that this game has a unique equilibrium in which all opportunists who violate the norm will choose the same extraction level. For reasons discussed above, the extraction level of violators will exceed that of those individuals (some of whom may be opportunists) who are in compliance with the norm.

The equilibrium number of violators will depend, among other things, on the severity of the sanction that reciprocators impose and it can be shown that the equilibrium number of violators is nonincreasing in the severity of the sanction. This is illustrated in Figure 2 for a particular specification of the model (with one reciprocator in a group of thirty individuals). The relationship between the number of violators and the severity of the sanction is nonlinear. A relatively small sanction can achieve some compliance, and the extent of compliance rises rapidly with the severity of the sanction at first. However, achieving complete or almost complete compliance requires very substantial increases in sanction severity. The reason is because increased compliance by others reduces the incremental cost of extraction and therefore raises the incentives to violate the norm. To counteract this requires the penalty from violation to rises commensurately.

Not all opportunists need receive the same payoff since the payoffs from compliance and violation are not necessarily equal in equilibrium. All opportunists earn more than reciprocators, however. This is the case because compliance is an option that opportunists may choose to exercise, and since they do not engage in monitoring or enforcement, compliance always yields opportunists a greater payoff than reciprocators can ever attain. Hence if opportunists choose to violate the norm they do so in the expectation that this will be at least as profitable as compliance, and hence strictly more profitable than the behavior of reciprocators. This raises the question of how reciprocators can survive under evolutionary pressure.

3 Evolution

Suppose that groups are formed by randomly sampling individuals from a large global population, a certain proportion of which are reciprocators. Groups formed in this manner will show some variation in composition directly as a result of randomness in the sampling process. If the global population share of reciprocators is close to zero, there will be a very high probability that most communities consist entirely of opportunists and most reciprocators will find themselves in communities in which no other reciprocators are present. Similarly, if the global population share of reciprocators is close to one, most groups will consist exclusively of reciprocators and most opportunists will find themselves in groups without other opportunists. For intermediate values of the global population composition there will be greater variety across groups and most groups will consist of a mixture of reciprocators and opportunists.

The average payoff obtained by opportunists in any given group is fully determined by the composition of the group. Hence the average payoff to opportunists in the population as a whole is obtained by taking a weighted average of opportunist payoffs, with the weight applied to each type of group being proportional to the probability with which that type of group will form. The same procedure applied to reciprocator payoffs yields the average payoff to reciprocators in the population as a whole. When these average payoffs differ, the population composition itself will change. We assume that the dynamics of the population composition are such that the type with the higher payoff grows relative to the type with the lower payoff (a special case of this is the replicator dynamics). We are interested in identifying stable rest points of this dynamic process with a view to identifying whether or not reciprocators can be present at such states.

Consider first a population consisting only of opportunists. Can reciprocators invade such a population under the evolutionary dynamics? Note that when the global reciprocator share is small, almost all reciprocators find themselves groups with exactly one reciprocator, while almost all opportunists find themselves in groups with *no* reciprocators. In groups of the former type reciprocators necessarily obtain lower payoffs than do opportunists (regardless of the extent of compliance). However, does not imply that a population of opportunists must be stable. Such a population will be *unstable* as long as reciprocators obtain greater payoffs in groups consisting of a single reciprocator than do opportunists in groups consisting of no reciprocators. This is clearly possible only if the presence of a single reciprocator induces at least some opportunists to choose compliance, and this in turn depends on the severity of the sanction.

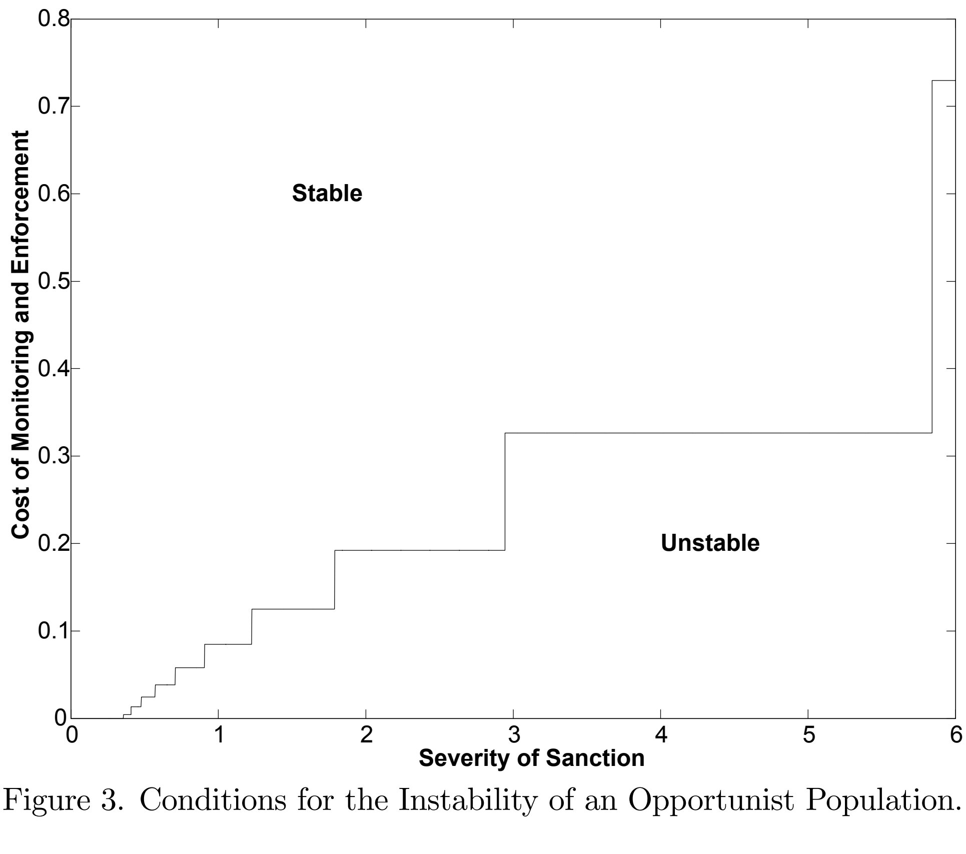

Figure 3. Conditions for the Instability of an Opportunist Population.

It can be shown that if the severity of the sanction falls below some threshold (which depends on group size and the cost parameter), then an opportunist population is necessarily stable. On the other hand, if the severity of the sanction exceeds this threshold, then an opportunist population will be invadable if the cost to reciprocators of imposing sanctions is sufficiently small. In particular, increasing the severity of sanctions increases or leaves unchanged the range of costs that are consistent with the instability of the opportunist population. However, there is a bound that the enforcement cost cannot exceed if an opportunist population is to be invadable, no matter how great the severity of sanctions happens to be. Figure 3 illustrates this for a particular specification of the model.

While an opportunist population may or may not be stable, a population consisting of reciprocators alone is unstable for all parameter values. The reason for this instability is the following. As the global reciprocator population share approaches one, reciprocators almost certainly find themselves in homogeneous groups in which each person complies with the norm and pays the cost of monitoring, while opportunists almost certainly find themselves in groups in which they are the only opportunist. Since they have the option of complying with the norm and escaping both the monitoring cost and the sanction, they can guarantee for themselves a payoff strictly greater than that which reciprocators get in all-reciprocator groups. Since this is feasible, their optimal choice must yield them at least this amount. Hence opportunists have a greater expected payoff than reciprocators when they are sufficiently rare in the global population.

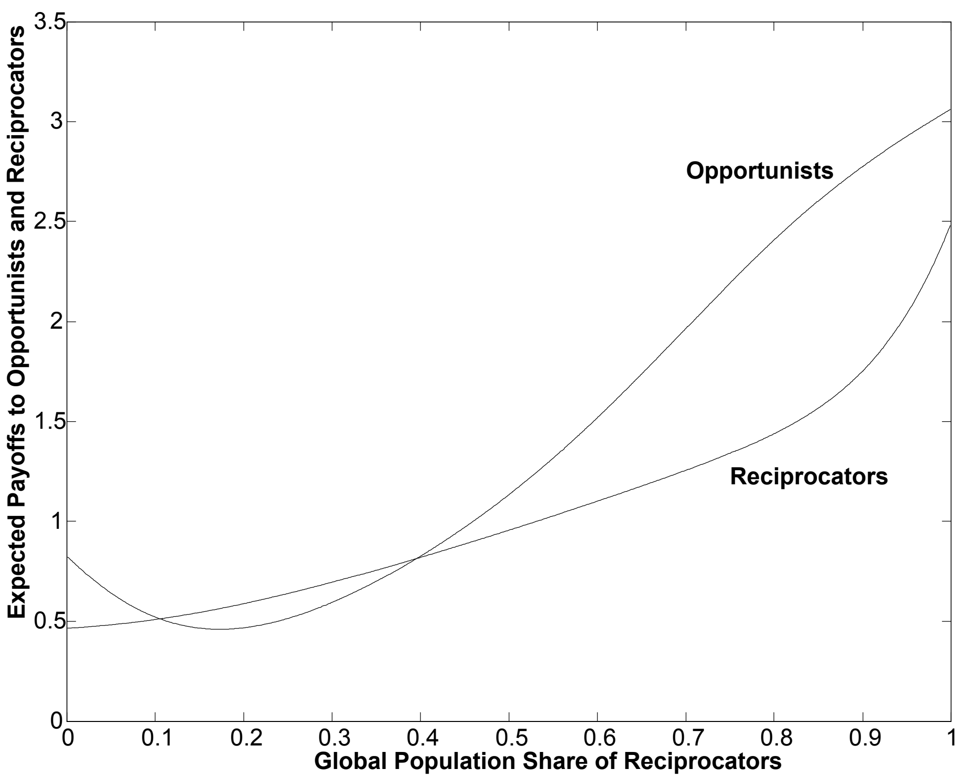

Figure 4. Multiple Stable Steady States.

For those parameter values which render an opportunist population unstable, the only stable states will be polymorphic (that is, will consist of a mixture of the two types). Polymorphic states can also arise when an opportunist population is *stable*, and it is not difficult to find parameter ranges consistent with two or even three stable states. Figure 4 shows how the average payoffs obtained by opportunists and reciprocators vary with the population share of the latter in the case of one such example. Aside from the stable state in which only opportunists are present, there is a second stable state in which about forty percent of the population is composed of reciprocators. In fact it is easy to find specifications in which three stable states exist, one of which consists almost exclusively of reciprocators.

The reason why a mixture of reciprocators and opportunists can be stable even when a population consisting only of opportunists is itself stable is subtle. If the severity of sanctions is insufficiently great, a single reciprocator in a group of opportunist will induce little or no compliance, and opportunists will outperform reciprocators when the population share of the latter is small. However, when the population share of reciprocators is not too small, most groups in which reciprocators find themselves will also contain other reciprocators, and in such groups there may be significant compliance. Opportunists will do even better that reciprocators in any such group, but even with random group formation, the probability with which an opportunist finds herself in a group with significant compliance will be somewhat lower than the probability with which reciprocators find themselves in such groups. This effect can outweigh the effect of greater opportunist payoffs in each group, and permit a mixed population to be stable.

This evolutionary theory of reciprocity is based on the power of *commitment*. Reciprocators are able to influence the behavior of opportunists in their group because they can credibly commit to punishing them if they violate the norm of limited resource extraction. Their commitment to do so is credible because they are strong reciprocators who prefer to punish violators even at some material cost to themselves. As a result, the disadvantage faced by reciprocators within their group can be outweighed by the fact that groups in which they are present can be significantly more successful than those in which they are absent. In the next section we review other approaches to the evolution of strong reciprocity that do not rely on commitment but rather on assortative interaction or parochialism.[6]

4 Assortation, Parochialism, and Identifiability

The preceding analysis was based on the hypothesis of random (non-assortative) group formation. If, instead, group formation is sufficiently assortative, stable norm compliance can occur even in the absence of a sanctioning mechanism. To take an extreme case, suppose that there were perfect assortation so that all groups were homogeneous. In this case each opportunist would be in a group in which all appropriators extract opportunistically, while each reciprocator would be in a group in which all appropriators extract efficiently. Reciprocators would obtain greater net benefits and opportunists would be displaced under evolutionary selection. It is easily seen that the same outcome arises if there is a sufficiently high degree of assortative interaction.[7]

[6] The section to follow draws on our considerably more extensive survey (Sethi and Somanathan, 2000). Other evolutionary models of reciprocity that rely on the power of commitment include Güth and Yaari (1992), Güth (1995), Sethi (1996), Huck and Oesschler (1999) and Friedman and Singh (1999). Gintis (2000) and Sethi and Somanathan (2001) analyze models in which both commitment (the power to influence the actions of others) and parochialism (the conditioning of one's behavior on the composition of one's group) play a role.

[7] This is, of course, analogous to Hamilton's argument that an altruistic gene will spread in a population if individuals share a sufficiently high proportion of their genes on average with those with whom they interact

How might assortative interaction among unrelated individuals arise? One possibility is that group formation results from a process of conscious choice in which reciprocators seek out those of their own type. Even if individuals of all types prefer to be in groups consisting largely of reciprocators, this will result in assortative interaction as long as reciprocators avoid interaction with opportunists. Endogenous group formation along these lines requires some degree of type identifiability, for instance through a signal by means of which reciprocators can be identified. When the signal is informative but imperfect, some opportunists will appear to be reciprocators and vice versa. The resulting sorting process leads to partial assortation: reciprocators are more likely to be matched with other reciprocators than with opportunists. Opportunists who happen to be matched with reciprocators do extremely well because they violate the norm while others in their group are in compliance. However, as long as the degree of assortation is sufficiently great, this advantage can be swamped by the disadvantage that opportunists face in being more likely to be matched with other opportunists. If, in addition, the process of sorting on the basis of signal observation is costly, then the long run population will consist of a mixture of types. The intuition for this is that when most members of the population are reciprocators, then investment in sorting not worthwhile and individuals forego the opportunity to seek out reciprocators and avoid opportunists. This allows the share of opportunists to grow until a point is reached when reciprocators find investment in sorting to be worthwhile.[8]

A less direct route to assortative interaction occurs when individuals may be *ostracized* from groups for noncompliance with social norms. In this case, opportunists must take into account not simply the direct payoff consequences of norm compliance and violation, but also the payoff implications of possible detection and expulsion. Since opportunists violate norms with greater frequency than do reciprocators, they will be expelled with greater likelihood. The result is assortative interaction: reciprocators are more likely than opportunists to be in a group with a large proportion of reciprocators. This compensates for the losses incurred by costly sanctioning of noncooperative behavior and both types can coexist in the long run.[9]

Even in the absence of assortative interaction, reciprocity can survive if individuals condition their *behavior* on the distribution of types in their group. We refer to this dependence of actions on the group composition as parochialism. The basic idea can be illustrated by considering the extreme case in which reciprocators comply with the norm and engage in monitoring and enforcement only if they are present in sufficiently large numbers to ensure complete compliance on the part of opportunists. In this case the behavior (and hence the payoffs) of opportunists and reciprocators are identical in groups containing an insufficient number of reciprocators. The remaining groups achieve norm compliance and significantly higher payoffs, although opportunists in such groups escape the cost of monitoring and hence have a payoff advantage over reciprocators. If the cost of monitoring is sufficiently small, this advantage to opportunists will be outweighed by the fact that reciprocators are more likely to find themselves in groups which achieve norm compliance and efficiency, even under non-assortative group formation. In this case reciprocators will survive and spread in a pop-

(Hamilton, 1964).

[8]This model of partial assortation on the basis of signalling is due to Frank (1987, 1988); see also Guttman (1999). For a model in which prior cooperative acts are themselves used as signals, see Nowak and Sigmund (1998).

[9]See Bowles and Gintis (2000) for a model along these lines.

ulation consisting largely of opportunists, just as they would under assortative interaction. Suppose further that the monitoring costs incurred by reciprocators in groups in which they predominate lower their payoffs below those of opportunists in these groups. If opportunists are rare, most groups containing both types will be of this kind, and opportunists will therefore invade a population of reciprocators. In this case, the model predicts the evolution of a mixed population.[10]

The preceding discussion has been based on the assumption that individuals know the composition of their group, as would be the case if reciprocators and opportunists could be distinguished by some observable trait. In this situation, an opportunist who carried the trait identifying reciprocators would outperform identifiable opportunists, and would gradually displace the latter in the population. As this happened, however, it would generate selection pressure favoring reciprocators who could distinguish themselves from the disguised opportunists. Reciprocators who evolved a signal that achieved this objective would reap the gains from efficient norm compliance in the presence of their own type. Hence, rather than assuming that reciprocators and opportunists are either perfectly distinguishable or perfectly indistinguishable, it is more realistic to assume that they are neither. As in the earlier discussion of assortative interaction, this can be done by supposing that prior to choosing actions each individual emits a signal with some fixed probability that depends on the individual's type. Specifically, suppose that reciprocators are more likely to emit the signal than are opportunists. After the signalling phase, each member of the group updates their assessment of the probability distribution describing the composition of the group. When the global population consists almost exclusively of opportunists, it is extremely likely that even a person who emits the signal is an opportunist. This follows from the fact that the fraction of the population who are opportunists with signals will be much larger than the fraction of the population who are reciprocators with signals. The signal then conveys almost no information, and opportunists will not be deterred from over-extraction by the prospect of punishment even when they are matched with a person with a signal. Recognizing this, reciprocators will behave exactly like opportunists when the opportunist population share is large. Thus both types ignore the signal, choose the same inefficient extraction level, and get the same payoff.

Now consider the other extreme case of a population consisting almost exclusively of reciprocators. Again, the signal will convey virtually no information since it is extremely likely, regardless of whether or not the signal is observed, that each player in one's group is a reciprocator. In this situation, if reciprocators were to engage in monitoring, then opportunists would always comply with the norm, and get higher payoffs than reciprocators by escaping the monitoring cost. If, on the other hand, reciprocators did not monitor, then opportunists would extract more than the norm, thus getting higher payoffs than reciprocators. In either case, we see that opportunists will always be able to invade a reciprocator population. (Reciprocators will always comply with the norm since they expect with near-certainty that the other group members are fellow reciprocators.)

However, there will exist an intermediate range for the global population composition such that the signal does convey useful information. This case is complicated and we illustrate it under the simplifying assumption that the group size is two. Suppose that reciprocators who

[10] Gintis (2000) models this effect in an empirically motivated model of public goods provision.

emit a signal comply with the norm and engage in monitoring, and that reciprocators who do not emit signals never monitor, and comply if and only if they are matched with someone who emits a signal. Given this behavior of reciprocators, the best response of opportunists, provided the damage from punishment is high enough, is to comply when their partner emits a signal and to extract more than the norm when their partner emits none. In this case players emitting signals do much better than those emitting none. Within this group, opportunists obtain greater payoffs than reciprocators since they never monitor and comply only when they observe a signal from their partner. Nevertheless, this advantage can be outweighed by the fact that reciprocators are more likely to emit signals in the first place.[11]

Can reciprocity be evolutionarily stable even in the absence of commitment, assortation or parochialism? If the costs of monitoring and sanctioning are negligible when there is complete norm compliance, there can be stable groups consisting of a mixture of reciprocators and pure cooperators (who comply with but do not enforce the norm). This stability is of a rather tenuous nature since it can be disrupted by periodic appearance of individuals who violate the norm and are punished by reciprocators for doing so. If, however, behavior is transmitted across generations through a cultural process that is partly *conformist* (in the sense that widespread behaviors are replicated at greater rates than less common but equally rewarding behaviors), then such groups can be stable in a more robust sense. Conformist transmission, however, can result in the stabilization of virtually any behavioral norms, including those that are anti-social and inefficient. One way to reduce the multiplicity of potential outcomes is to allow for cultural selection to operate in *structured populations*. In this model, groups are located in accordance with a spatial pattern in which each group has well-defined neighbors. Members of groups which exhibit efficient norms will enjoy higher material payoffs than members of groups which do not, and such norms may therefore spread through the population by the imitation of successful practices found in neighboring groups. The study of structured populations holds considerable promise in helping identify additional mechanisms for the survival and spread of strong reciprocity.[12]

One further direction in which work on the evolution of reciprocity can profitably proceed is the following. Several researchers have recently provided parsimonious representations of preferences that can be used to account simultaneously for data from a variety of strategic environments. These specifications are free of any particular experimental context, and reflect concerns for distribution, efficiency and reciprocity.[13] Evolutionary models can build on this literature by shifting focus from the analysis of behavioral norms in particular environments to the emergence and stability of general purpose rules that are equipped to deal with multiple and novel situations.

[11] See Frank (1987), Robson (1990) and Guttman (1999) for further discussion and variations on the theme of signalling.

[12] Models in which stable mixtures of reciprocators and pure cooperators can arise include Axelrod (1986) and Sethi and Somanathan (1996); see Gale, Binmore and Samuelson (1995) for similar findings in a different context. A discussion of conformist transmission and its implications may be found in Boyd and Richerson (1995). The model of structured populations mentioned here is due to Boyd and Richerson (2000).

[13] Important contributions include Rabin (1993), Levine (1998), Fehr and Schmidt (1999), Bolton and Ockenfels (2000), Falk and Fischbacher (1998), Dufwenberg and Kirchsteiger (1998), and Charness and Rabin (2000).

5 Conclusions

Social norms that have evolved in a particular economic environment often continue to govern behavior in other contexts. Even as the relative economic importance of traditional local commons has diminished with the expansion of state and private property, norms of restraint and enforcement that arose as a substitute for governments and markets in such environments continue to make their presence felt in more modern institutions such as firms, unions, and bureaucracies. Compliance with such norms often results in greater economic efficiency relative to the case of opportunistic behavior. Viewed in this light, norms of reciprocity are an important component of social capital, and an understanding of their origins and persistence may help to prevent their erosion.

The literature on the evolution of strong reciprocity is a patchwork of models each of which emphasizes a different mechanism under which reciprocators can survive in competition with purely opportunistic individuals. We have identified three broad themes in commitment, parochialism and assortation, which appear repeatedly in the literature. These effects, separately or in combination, are largely responsible for the departures from narrow self-interest that humans display in the experimental laboratory and in daily life.

Appendix

The claims made in Sections 2-3 in the text are proved formally below. The common pool resource game involves n players with appropriator i choosing extraction x_i at a cost $(aX)\,x_i$ where $X = \sum_{i=1}^{n} x_i$ denotes aggregate extraction. The payoffs of individual i are

$$\pi_i = x_i\,(1 - aX)\,. \tag{1}$$

The efficient level of aggregate extraction maximizes aggregate payoffs $\sum_{i=1}^{n} \pi_i = X\,(1 - aX)$ and is given by

$$X^* = \frac{1}{2a}. \tag{2}$$

Reciprocators comply with and enforce a norm that prescribes, for each individual, the extraction level

$$x^r = \frac{1}{n} X^* = \frac{1}{2an}. \tag{3}$$

Reciprocators monitor others at a cost $\gamma > 0$ and are able to detect and sanction all violators. Violators incur a cost δ as a result of each sanction. Opportunists simply choose extraction levels that maximize their payoffs (1). Let r denote the number of reciprocators in the community. A opportunist i who has chosen to extract optimally (and hence violate the norm) must choose a level of extraction

$$x_i = \frac{1 - aX}{a}.$$

Since X is common to all individuals, all opportunists who violate the norm will choose the same extraction level. Let x^v denote this level, and let $v \leq n - r$ the number of opportunists who choose it. Then

$$X = (n - v)\,x^r + v x^v.$$

Using the two previous equations we obtain

$$a x^v = 1 - a\left((n - v)\,x^r + v x^v\right)$$

which, using (3), simplifies to yield

$$x^v = \frac{1}{2an}\left(\frac{n + v}{1 + v}\right) \tag{4}$$

Aggregate extraction is

$$X = (n - v)\,\frac{1}{2an} + v\frac{1}{2an}\left(\frac{n + v}{1 + v}\right) = \frac{1}{2an}\left(\frac{n + v\,(2n - 1)}{1 + v}\right) \tag{5}$$

Using (1), (4), and (5) and taking into account the sanctions imposed on violators, we get

$$\pi^v = x^v(1-aX) - \delta r = \frac{1}{4a}\frac{(n+v)^2}{n^2(1+v)^2} - \delta r \tag{6}$$

where π^v is the payoff from violation. The payoff from compliance is

$$\pi^c = x^r(1-aX) = \frac{1}{4a}\left(\frac{n+v}{n^2(1+v)}\right). \tag{7}$$

In equilibrium, a unilateral deviation should not benefit any opportunist. If $v \in [1, n-r-1]$, this implies the following conditions

$$\frac{1}{4a}\left(\frac{n+v}{n^2(1+v)}\right) \geq \frac{1}{4a}\frac{(n+v+1)^2}{n^2(2+v)^2} - \delta r \tag{8}$$

$$\frac{1}{4a}\frac{(n+v)^2}{n^2(1+v)^2} - \delta r \geq \frac{1}{4a}\left(\frac{n+v-1}{n^2 v}\right) \tag{9}$$

The first states that an opportunist in compliance cannot profit by switching to noncompliance; the second that an opportunist in violation cannot profit by switching to compliance. If $v = 0$ in equilibrium only the former condition need be satisfied, and if $v = 1$ only the latter.

The parameters n, a, and δ and the number of reciprocators r define a game played by the $n-r$ opportunists who choose their extraction levels strategically, with the number of violators v being determined in equilibrium. Let this game be denoted $\Gamma(n, a, \delta, r)$. We then have:

Proposition 1 *Every game $\Gamma(n, a, \delta, r)$ has a unique equilibrium. The equilibrium number of violators v is nonincreasing in δ.*

Proof. From (8-9), the number of violators v at any asymmetric equilibrium must satisfy

$$F(v) \leq \delta \leq G(v) \tag{10}$$

where

$$F(v) = \frac{1}{4ar}\frac{(n+v+1)^2}{n^2(2+v)^2} - \frac{1}{4ar}\left(\frac{n+v}{n^2(1+v)}\right)$$

$$G(v) = \frac{1}{4ar}\frac{(n+v)^2}{n^2(1+v)^2} - \frac{1}{4ar}\left(\frac{n+v-1}{n^2 v}\right)$$

Note that $F(v-1) = G(v)$. Hence (10) defines a sequence of intervals $\{[F(v), F(v-1)]\}_{v=1}^{n-r-1}$ such that there is an asymmetric equilibrium with v violators if and only if $\delta \in [F(v), F(v-1)]$. If δ does not fall within any of these intervals, then equilibrium is symmetric. If $\delta > F(0)$, there is no violation in equilibrium, while if $\delta < F(n-r)$ there is no compliance in equilibrium. Note that raising δ lowers or leaves unchanged the equilibrium value of v. ■

Proposition 1 allows us to write the number of violators as a function of the number of reciprocators $v = v(r)$. This in turn defines aggregate extraction, and the payoffs from compliance and violation as functions of r. The payoff obtained by reciprocators is therefore

$$\pi^r(r) = \pi^c(r) - \gamma. \tag{11}$$

and the mean payoff received by opportunists is

$$\pi^m(r) = \frac{v(r)\pi^v(r) + (n - r - v(r))\,\pi^c(r)}{n - r}. \tag{12}$$

Suppose that the share of reciprocators in the population as a whole is given by ρ, and that this population is randomly distributed across communities. The probability that a community formed in this manner will contain precisely r reciprocators is given by

$$p(r, \rho) = \frac{n!}{(n-r)!r!}\rho^r (1-\rho)^{n-r}.$$

The expected payoffs of reciprocators and opportunists in the population as a whole is given by

$$\begin{aligned}
\bar{\pi}^r(\rho) &= \frac{\sum_{r=1}^{n} p(r,\rho)\pi^r(r)}{\sum_{r=1}^{n} p(r,\rho)} \\
\bar{\pi}^m(\rho) &= \frac{\sum_{r=0}^{n-1} p(r,\rho)\pi^m(r)}{\sum_{r=1}^{n} p(r,\rho)}
\end{aligned}$$

The mean payoff in the population as a whole is simply

$$\bar{\pi}(\rho) = \rho\bar{\pi}^r(\rho) + (1-\rho)\,\bar{\pi}^m(\rho).$$

Suppose that the evolution of the population share ρ is governed by the replicator dynamics

$$\dot{\rho} = (\bar{\pi}^r(\rho) - \bar{\pi}(\rho))\,\rho.$$

Then we have

Proposition 2 *Suppose n and a are given. Then there exists $\bar{\delta} > 0$ such that an opportunist population is stable if $\delta \leq \bar{\delta}$. If $\delta > \bar{\delta}$, then there exists a nondecreasing and bounded function $\bar{\gamma}(\delta)$ such that an opportunist population is stable if and only if $\gamma > \bar{\gamma}(\delta)$.*

Proof. The stability of $\rho = 0$ depends on whether or not $\pi^m(0)$ is greater than $\bar{\pi}^r(1)$. This is because

$$\begin{aligned}
\lim_{\rho\to 0} \bar{\pi}^m(\rho) &= \pi^m(0) \\
\lim_{\rho\to 0} \bar{\pi}^r(\rho) &= \pi^r(1)
\end{aligned}$$

All opportunists violate the norm when $r = 0$, so in this case $v = n$ and

$$\pi^m(0) = \pi^v(0) = \frac{1}{4a}\frac{(n+n)^2}{n^2(1+n)^2} = \frac{1}{a(1+n)^2}.$$

From (11) and (7), we have

$$\pi^r(1) = \frac{1}{4a}\left(\frac{n+v}{n^2(1+v)}\right) - \gamma$$

Hence

$$\begin{aligned}\pi^r(1) - \pi^m(0) &= \frac{1}{4a}\left(\frac{n+v}{n^2(1+v)}\right) - \frac{1}{a(1+n)^2} - \gamma \\ &= \frac{1}{4}\frac{(n-1)(n^2-n-3vn-v)}{an^2(1+v)(1+n)^2} - \gamma\end{aligned}$$

The first term is positive if and only if $n^2 - n - 3vn - v > 0$. This requires

$$v < \left(\frac{n-1}{3n+1}\right) n$$

There exists $\bar{\delta} > 0$ such that the above will not be satisfied for any $\delta < \bar{\delta}$, in which case the opportunist population must be stable. If $\delta > \bar{\delta}$, then stability holds if and only if $\gamma < \bar{\gamma}$ where

$$\bar{\gamma} = \frac{1}{4}\frac{(n-1)(n^2-n-3vn-v)}{an^2(1+v)(1+n)^2}.$$

The right hand side of the above expression is decreasing in v. Since v is nonincreasing in δ, $\bar{\gamma}$ is nondecreasing in δ. ■

Finally we have

Proposition 3 *A reciprocator population is unstable for all parameter values.*

Proof. The stability of $\rho = 1$ requires $\pi^r(n)$ to be greater than $\pi^m(n-1)$. When $r = n-1$, the single opportunist can comply with the norm and obtain a payoff $\pi^r(n) + \gamma$. Since this payoff is feasible, under optimal choice $\pi^m(n-1) \geq \pi^r(n) + \gamma > \pi^r(n)$. Hence $\rho = 1$ is unstable. ■

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