COLLECTIVE ACTION AND NETWORK STRUCTURE*

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I develop and analyze a mathematical model describing the relationship between individual contributions to a collective good and the network of social relations that makes these contributions interdependent. Starting from the assumption that actors respond to the contributions of others because of efficacy concerns and norms of fairness, I derive predictions about the impact of network structure on total contributions. Network density and size influence collective action outcomes in dramatically different ways, depending on the structural position of those who make unconditional contributions. Moreover, these effects are highly nonlinear, suggesting that the impact of social ties on collective action may be quite sensitive to mobilization contexts.

Most students of collective action agree that social ties occupy a central place in explanations of how groups overcome the free-rider problem. Taking a cue from the theoretical work of Oberschall (1973) and Tilly (1978), empirical studies of social movements point increasingly to the role of networks of social relations in recruitment and mobilization (Snow, Zurcher, and Ekland-Olson 1980; McAdam 1986; Fernandez and McAdam 1988; Gould 1990). Theoretical work by Marwell, Oliver, and their colleagues has shown that paying attention to network density and centralization provides considerable leverage in making predictions about mobilization outcomes (Oliver, Marwell, and Teixeira 1985; Marwell, Oliver, and Prahl 1988; Oliver and Marwell 1988).

Underlying this focus on networks is the recognition that social ties make individuals' decisions about participating in collective action interdependent. A basic tenet of Olson's (1965) formulation of the free-rider problem is that a rational actor will abstain from contributing to a public good if his or her contribution has a negligible impact on the total amount of the good produced (and consequently a negligible impact on his or her consumption of the good). But if these decisions are not independent (if one actor's contribution makes another actor's contribution more likely), the total benefit resulting from an individual's decision to contribute may be considerably greater than his or her cost of contributing.[1]

Recent discussions of this issue (Marwell et al. 1988; Macy 1991a, 1991b; Gamson 1990) highlight the role that interdependent decisions play in motivating individuals to participate in collective action in the absence of selective incentives. Opp (1989) suggested that committed actors revise their perceptions of efficacy upward because of cognitive dissonance when they realize that others may abstain from collective action if they think their contributions will have little impact. Marwell et al. (1988) argued that, if individual actors ignore the possibility that others will provide a collective good for them, they will contribute to the good as long as total contributions are large enough to ensure that their share of the returns exceeds the cost. In a similar spirit, but slightly different vein, Macy (1991b) argued that actors do not act to maximize net rewards, but simply respond to positive and negative reinforcements measured in terms of changes in their share of the collective good (or bad). When collective outcomes are beneficial, shirkers raise their "thresholds" (Granovetter 1978), making future shirking even more likely, while cooperators lower their thresholds and thus be-

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[1] For instance, it may be rational to cooperate in Iterated Prisoner's Dilemma games because when players use some variation of the "tit for tat" strategy, the decision to cooperate or defect affects the other player's decision in later iterations (Axelrod 1984; Macy 1991a).

come more willing to cooperate; when collective outcomes are harmful, actors alter their thresholds in the opposite direction.

According to all three perspectives, contributions hinge on a crucial element of naiveté. For Opp, actors convince themselves that they can make a difference because it would be costly (in cognitive terms) to go on making contributions in the face of a contrary belief. In Macy's (1991b) account, actors simply do more of whatever appeared to work last time (or less of what did not work), regardless of whether there is any plausible causal connection between their own actions and the outcome. There *is* such a connection in the model, because thresholds make everyone's participation contingent on the overall rate of participation; but this causal link is invisible to each actor because his or her impact on the participation rate is small.[2] In the model described by Marwell et al. (1988), actors close their minds to the tempting option of shirking while others contribute.

In this article, I propose a formulation of the link between individual participation and collective efficacy that is predicated on different assumptions. When contributions fall short of the collective optimum, I argue, it is not necessarily because people are rewarded for free-riding. Conversely, when people do contribute, it is not necessarily because they have not considered the possibility of free-riding. Instead, I assume potential contributors keep all their options in mind, choosing among them on the basis of two simple concerns: norms of fairness that encourage individuals to match the contributions of others, and the desire to avoid making contributions that will be wasted. Both concerns push actors to attend to the behavior of others when making decisions about their own contributions.

Following a brief theoretical discussion, I develop a model relating individual decisions about participation in collective action to networks of social ties that inform actors about the behavior of others. Solving the model for equilibrium outcomes leads to the prediction that alternative network structures exert profoundly different and occasionally counterintuitive effects on collective action, depending on the structural position of "volunteers." Specifically, when volunteers are centrally located, dense networks offer far dimmer prospects for mobilization than sparse networks. In addition, group size may affect mobilization positively, negatively, or not at all, depending on density. Finally, tendencies toward intransitivity enhance mobilization by contributing to connectedness in relatively sparse networks. All of these effects, and the complex interactions among them, show that an actor's impact on the behavior of others depends not only on overall network structure, but also on his or her position within that structure.

THEORY

Suppose the residents of Maple Street generally agree that they would like it to be cleaner than the city keeps it. Olson's (1965) logic of collective action predicts that suboptimal levels of this "good" (cleanliness) will be produced unless there is at least one individual who values it sufficiently to bear the cost alone, or unless selective incentives are provided that make individual contributions worthwhile. Worse yet, even if there are people who value clean streets enough to benefit by doing the work themselves, they may still prefer to do nothing in the hope that someone else will do it first. This is the essence of "Volunteer's Dilemma": As worthwhile as it might be to do the work, it would be even nicer to have someone else do it (Diekmann 1985).

Few social scientists believe that individuals are pure rational egoists, particularly since collective action occurs more frequently than the rational choice framework would predict. This is why models like those of Macy (1991a, 1991b), Oliver and Marwell (1988), and Marwell et al. (1988) relax the rational-choice assumptions underlying economists' work on public goods. The advantage of such models is that they can explain the production of collective goods even in the absence of formal sanctioning mechanisms (Heckathorn 1988, 1990), but they do not err in the opposite direction insofar as they also predict suboptimal outcomes in a variety of situations.

For instance, in the hypothetical case just described, Macy's (1991) model would predict

[2] Macy (1991b) noted that actors' initial thresholds may reflect attachment to a norm of fairness — a willingness to contribute only if a sufficient number of others are contributing. But *changes* in actors' thresholds are modeled exclusively as a function of positive and negative reinforcements.

that some residents might end up participating in a cleanup effort if chance produced enough simultaneous contributions to have a noticeable effect. If the benefit were sufficiently large, these contributors could eventually lower their thresholds enough to "lock in" a sustained effort, even as shirkers, reassured by the success of their free-riding, settled further into idleness by increasing their thresholds. (Some of these shirkers might, in fact, have had initially low thresholds; their start down the road to chronic shirking begins with positive reinforcement incurred during a randomly produced moment of nonparticipation.)

The model I propose retains the assumption that individuals are not pure utility maximizers, in particular because I argue that fairness norms play a central part in the production of collective goods (Elster 1989). At the same time, however, I assume that decisions to contribute are informed by expectations of individual efficacy. People may be perfectly willing to contribute something to a collective good, but unless they are reasonably sure their contributions will not be wasted, they will wait to see what others do. That is, even if they are not tempted to free-ride, individuals may be reluctant to invest in a collective good unless it seems likely that enough others will also invest to produce positive results.

Imagine, then, that none of Maple Street's inhabitants has so far done anything to improve the street's appearance. Most think it would be unfair if they had to shoulder the burden alone; moreover, if the task of cleaning is large, the total benefit of one person's efforts will be small. But as long as there is at least one person for whom some small effort is worthwhile (perhaps because he or she values clean streets more), the decision framework for everyone else changes. Suppose, for example, that Betty decides to spend an hour picking up refuse. This initial effort increases the value of further efforts: Others will now be more enthusiastic about sweeping, planting ivy, or just picking up trash (because a single discarded object now represents a greater percentage of the total remaining). Stated more formally, Betty's effort has increased the marginal returns to the group that would accrue from further contributions.

Note that, if everyone else were a rational egoist, these increasing marginal returns would make no difference. The contribution already made would only further persuade shirkers that the best thing to do is wait around for someone else to do the (now more valuable) work. But Betty's effort has another effect as well: In the presence of a norm of fairness, everyone now has a reason to match her contribution. For the same reason that people dislike being exploited (i.e., they believe exploitation is unfair), they do not want to be perceived, and potentially ostracized, as exploitative. Stated more positively, seeing others contribute should motivate actors to contribute their share. Thus, in general, if contributions are visible, then noncontributors may be subject to normative social pressures to alter their behavior.[3] That this is far from a trivial concern was clearly demonstrated by the emotional reactions of subjects in Dawes, McTavish, and Shaklee's (1977) experiment on communication and cooperation in social dilemmas. Cooperators often reacted with considerable anger to the defection of other subjects, either shouting at them or refusing to speak with them afterwards. Even when the identities of defectors were not announced, cooperators were visibly upset by what they considered to be treachery. For their part, defectors waited until others had left before leaving the experiment site.

In short, if at least one actor has already made a contribution, other actors have two reasons — one normative and one instrumental — to make contributions of their own. Neither reason accomplishes much by itself: Normative pressure to contribute should have little impact if elicited contributions will be completely wasted, while increasing marginal returns will only reinforce the waiting game in the absence of fairness norms.

Nonexperimental research suggests that considerations of this kind often enter into people's decisions to participate in collective action. For instance, McAdam's (1986) study of participants in the Mississippi Freedom Summer project found that pairs or groups of friends of-

[3] This could create a second-order free rider problem insofar as people might be unwilling to expend the effort to pressure others (Oliver 1980). But it seems doubtful that individuals would necessarily perceive this "effort" as costly: Pressuring others to contribute to a collective good may actually be rewarding in itself because it permits contributors to represent themselves as praiseworthy, conscientious citizens. Fairness norms make social influence both possible and efficacious as a weapon against free-riding.

ten decided to participate after an "I'll go if you go" discussion. Applicants to the project felt that (1) participation would be more efficacious if others also participated, and (2) it would be embarrassing to withdraw from the project if one's friends had the courage and commitment to stay with it. Gould (1990) found that participants in the Paris Commune of 1871 routinely reported that pressure from neighbors in the Paris National Guard made it difficult to avoid serving in the neighborhood-based insurgent militia organization. Hirsch (1990) suggested that participants in an anti-apartheid divestiture movement understood their own participation as a response to the apparently altruistic participation of others and to the change in their expectations of success based on this observation.

Boundary Conditions

The arguments I have advanced are clearly not applicable to all social dilemma situations. The most salient boundary condition is *efficacy*: Although it is not necessary to assume that actors can precisely estimate the group's marginal returns to contributing, they must at least perceive a difference in the potential impact of their own efforts based on the efforts of others. In addition to scenarios like the Maple Street example, it is reasonable to expect such a perception in any situation in which there is no explicit benefit function but where results depend on an indispensable first step. Signing a petition, for instance, is not only pointless but impossible unless someone has already invested the time in writing one. Similarly, large protest demonstrations almost inevitably begin (at least in Western societies) with an application for an official permit, followed by advertisement and recruitment efforts, and finally by direct participation. At each step in the process, new contributions are efficacious only to the extent that previous efforts have already been made. The increasing importance of professionalized social movement organizations derives from the same principle, which explains why direct-mail solicitations focus so heavily on the value of small contributions given that movement activities are already organized and producing results.

The theory I propose, then, would not predict contributions in situations in which the volunteered efforts of a small number of people are insufficient to make the contributions of others seem worthwhile. This does not imply that the argument is incorrect in such situations, but rather that the model based on it leads to a prediction of low total contributions when initial contributions leave marginal returns unchanged. Here, normative pressure to contribute is simply outweighed by futility.[4]

A second boundary condition is that *initial contributions must represent sunk costs*, i.e., the model developed below assumes that volunteers will not or cannot retract their contributions if responses are not forthcoming. Otherwise, uncertainty about whether the volunteered contribution has been made in good faith may vitiate its impact; in response, the volunteer might reduce his or her investment, resulting in a self-fulfilling prophecy of failure. This means that instances of collective action in which mobilization attempts are backed up with promised contributions (rather than visible investments that have already been made) are less likely to exhibit the influence process hypothesized here. For instance, a pledge to spend one hour cleaning up Maple Street will do less to motivate others than an hour already invested.

The final boundary condition is that in order for fairness norms to influence behavior, *actors must perceive themselves as members of an identifiable collectivity* — even if this collectivity is defined merely as the total number of potential beneficiaries of the collective good. In the absence of such a collective identity, actors may have no reason to think of themselves as bound by a norm of fairness (or a norm against exploitation), at least with respect to the specific collective good in question (for recent discussions of the role of collective identities in social movements, see Gamson 1990; Melucci 1985). Residents of Oak Street presumably have no qualms about not contributing to the clean-up effort on Maple Street. On the other hand, collective identities need not be restricted in scope or impact to small, face-to-face groups. Finkel, Muller, and Opp (1989) found that the "duty to participate" played a significant role in decisions to join in anti-nuclear protests, despite the fact that duty was

[4] Most theoretical discussions, of course, make the same prediction; no one expects large contributions to collective goods that have little perceived chance of being provided.

construed in terms of national citizenship rather than membership in a local community. And recent debates on nationalism are predicated on the observation that membership in abstractly defined "imagined communities" (Anderson 1983) powerfully influences individual behavior (Gellner 1983; Hobsbawm 1990). In sum, the influence of norms of fairness presupposes the existence of a collective identity, but this stipulation does not restrict the model to small or close-knit groups.

THE MODEL

I begin by assuming that actors are influenced by a set of exogenous factors that determines the level at which they will make unconditional contributions to a specific collective action, i.e., contributions they are willing to make even if everyone else contributes nothing. For an actor, i, this initial expected contribution is denoted by x_i. Although one interpretation of x_i is that it represents the level at which actor i finds it rational to contribute (in terms of the individual benefit the contribution would confer) in the absence of contributions from others, this is not the only possible interpretation, nor is it necessary to the logic of the model. For instance, x_i might represent the amount actor i is willing to contribute through simple altruism, independent of the actual benefits the contribution might lead to.[5] In the analyses of the model presented below, x_i is set to 0 for all actors except one (the "volunteer").

The second key assumption is that actors alter their levels of contribution, denoted by c_i, based on the levels of contribution they observe among other actors. Knowing what others are likely to contribute tells a potential contributor two things: (1) how likely it is that a further contribution will have an effect, and (2) how his or her hypothetical contribution (which might be nothing) compares with the average contribution from everyone else.

Assume, then, that Betty (whom I denote formally with the subscript 1) is willing to contribute one hour of work to cleaning the street, even if everyone else contributes zero, while everyone else is unwilling to contribute anything if no one else does. (Formally, $x_1 = 1$, and $x_i = 0$ for $i > 1$.) Since Betty has nonetheless contributed something, everyone else has to reconsider his or her contribution level because the conditions under which each actor's contribution will be just x_i are not met. The central contention of my theoretical model is that, if individuals are exposed to each other's behavior, they will adjust their contributions to take account of the fact that one person is willing to contribute one hour even if no one else contributes. In this case, if everyone has contact with everyone else, each noncontributor will observe one person (Betty) who has contributed one hour and N – 2 persons who have contributed nothing, where N is the total number of actors.

Given that contributions total one hour for N actors, how do the others decide how much to contribute in response? A reasonable conception of a "fair share" would require an actor's contribution to be proportional to the total contributions summed across all other actors, divided by the total number of such actors, i.e., the average contribution each person observes from everyone else.[6] In the scenario under consideration, then, actors will initially modify their contributions in the following way:

$$c_i(t) = \frac{\lambda}{N-1}\sum_{j}^{N} c_j(t-1), \quad i \neq j, \qquad (1)$$

where c_i is the total amount actor i has contributed at time t, λ is a "discounting" parameter ranging between 0 and 1, and N is the total number of potential contributors. (At $t = 0$, Betty has contributed 1 hour, so $c_1(0) = x_1 = 1$.) When λ is close to 1, actors match the average contribution almost completely; thus λ reflects the strength of the influence actors exert on each other. For example, if λ is .9 and N is 20,

[5] Contributions by urban professionals to organizations that protect wildlife, for example, are more reasonably interpreted as altruistic than as attempts to invest in future rewards. It seems unlikely that Americans living in the northeastern United States actually expect to derive some future benefit by contributing money to protect spotted owls in the Pacific Northwest. The further argument could be made that contributors derive psychic benefits from the feeling that they are helping to solve a problem, but such an intepretation would stretch the notion of rational cost-benefit calculation to the point of tautology.

[6] A more complex formulation would make each actor's fair share proportional to his or her resource endowment. I restrict my attention here to the case in which actors' resources are roughly equal.

then the hour Betty contributes at time 0 (in conjunction with the observed noncontribution of everyone else) will persuade every other actor to contribute .9/19 = .047 hours at time 1. When $\lambda < 1$, actors only partially match the average of other actors; the influence actors exert on each other by virtue of their own contributions is systematically "discounted." This discounting is to be expected inasmuch as individuals tend to overestimate their own contributions to collective efforts relative to the contributions of others (see the research on "egocentric bias" reported by Ross and Sicoly 1979).

While everyone responds to Betty at time 1, she will not (at this time point) be persuaded to supplement her initial one-hour contribution because contributions from everyone else at time 0 totaled 0. That is, she has no reason to expect that further contributions will be efficacious unless she observes others who have contributed. (By hypothesis, the hour Betty initially plans to contribute is the amount she thinks is worthwhile to invest in the absence of contributions by others.) In any case, unless others catch up with her initial hour, Betty will not in general be subject to normative pressure to make further contributions. She may, however, contribute more time because of efficacy considerations or because of the enthusiasm sparked by the responses of others. I assume, therefore, that anyone who makes unconditional contributions may respond more slowly to subsequent contributions by nonvolunteers. As a result, Betty's subsequent contributions are subject to a further discounting, denoted by the parameter v.

Overall, then, the supplemental contribution each actor is willing to make at time t is the average expected contribution of everyone else at time $t - 1$, weighted by λ. For Betty, however, this average is weighted by $v\lambda$, where v is assumed to be less than or equal to unity.

The fact that individuals change the amount they contribute in response to Betty's contribution produces a feedback loop: The changes in c_i at time t require each actor at time $t + 1$ to revise his or her perception of what a fair share is. In addition, seeing that others besides Betty have made contributions changes each person's expectation about the efficacy of contributing further. This in turn results in a revision of c_i for each actor (now including Betty), which again changes everyone's expectations. Thus, the hour Betty contributes at time 0 persuades everyone to contribute something at time 1; actors respond to this influence process at time 2 by influencing each other further, and so on.

When $0 < \lambda < 1$, each of these successive adjustments to c_i is smaller than the last.[7] Consequently, the influence process leads actors to converge on a set of equilibrium contributions, c_i^*, which is given by

$$c_i^* = x_i + \frac{\lambda}{N-1}\sum_j^N \Delta c_j(1) + \frac{\lambda}{N-1}\sum_j^N \Delta c_j(2) + \ldots + \frac{\lambda}{N-1}\sum_j^N \Delta c_j(\infty) = x_i + \sum_{t=0}^{\infty} \Delta c_i(t), \tag{2}$$

where $\Delta c_i(t) = c_i(t) - c_i(t-1)$. Because $\Delta c_j(\infty) = 0$, I can also express each actor's equilibrium contribution as follows:

$$c_i^* = x_i + \frac{\lambda}{N-1}\sum_j^N c_j^*, \tag{3}$$

except for Betty, whose equilibrium contribution is

$$c_1^* = x_1 + \frac{v\lambda}{N-1}\sum_j^N c_j^*. \tag{4}$$

In other words, each actor's contribution at equilibrium is equal to his or her initial contribution added to the average equilibrium contribution for everyone else.[8] Given an initial set of volunteered contributions (the values of x_i), the model predicts that actors will influence each other's expected contributions until they arrive at a stable set of actual contributions that satisfies equations 3 and 4.

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[7] This is true even when $\lambda = 1$, as long as $v < 1$. Otherwise, contributions will continue to increase until new efforts are redundant.

[8] If total contributions are already large, actors can be expected to believe that further contributions will make no difference. That is, if the benefit function is S-shaped (Elster 1989; Macy 1991b), the marginal return to contributions will be small at high levels of provision. Equilibrium will therefore obtain either when the flat region of the benefit function is reached, or when contributions satisfy equations 3 and 4, depending on which occurs first.

Calculation of this equilibrium contribution, given the x_i, is straightforward. In the hypothetical example being considered, $x_i = 1$ for Betty (actor 1) and 0 for everyone else. Consequently, following equation 3,

$$c_1^* = \nu\lambda(c_\cdot^*) + 1, \quad (5)$$

where $c_\cdot^*$ is the equilibrium contribution for everyone but actor 1. (Note that everyone but Betty has the same equilibrium contribution, because each has $x_i = 0$ and each faces identical influences beginning with Betty's expected one-hour contribution. As a result, $c_\cdot^*$ is equal to the average contribution Betty observes among the other N – 1 actors.)

For everyone else,

$$c_i^* = c_\cdot^* = \lambda\left(\frac{c_1^*}{N-1} + \left(\frac{N-2}{N-1}\right)c_\cdot^*\right), \quad i > 1, \quad (6)$$

which averages Betty's equilibrium contribution with the equilibrium contributions of the other N – 2 actors. Substituting equation 5 into equation 6 gives

$$c_\cdot^* = \lambda\left(\frac{\nu\lambda c_\cdot^* + 1}{N-1} + \left(\frac{N-2}{N-1}\right)c_\cdot^*\right). \quad (7)$$

Rearranging to solve for $c_\cdot^*$ gives

$$c_\cdot^* = \frac{\frac{\lambda}{N-1}}{1 - \frac{\lambda}{N-1}(N + \nu\lambda - 2)}, \quad (8a)$$

which can also be written as

$$c_\cdot^* = \frac{\lambda}{(N-1) - \lambda(N + \nu\lambda - 2)}. \quad (8b)$$

The expression for the total equilibrium contribution across all actors, c_{tot}, then, is

$$\begin{aligned} c_{tot} &= c_1^* + (N-1)c_\cdot^* \\ &= \nu\lambda c_\cdot^* + 1 + (N-1)c_\cdot^* \quad (9) \\ &= (N - 1 + \nu\lambda)c_\cdot^* + 1. \end{aligned}$$

Substituting from equation 8b gives

$$c_{tot} = 1 + \frac{(N - 1 + \nu\lambda)\lambda}{(N-1) - \lambda(N + \nu\lambda - 2)},$$

which, after some algebra, gives

$$c_{tot} = 1 + \frac{\lambda}{(1-\lambda) + \frac{(1-\nu)\lambda}{N + \nu\lambda - 1}}. \quad (10)$$

So, to extend the above example, if N = 20, $\lambda = .9$, and $\nu = .5$ (i.e., if every hour contributed by the "average" alter leads ego to contribute 54 minutes, but people like Betty respond half as quickly), Betty's initial hour will result in a total equilibrium contribution across all 20 actors of 1/[(1 – .9) + (.45/19.45)] = 8.31 hours. Specifically, Betty will contribute 1.17 hours, while each of the other 19 actors will contribute .376 hours. Note that, as ν approaches unity, i.e., when Betty responds to others at nearly the same rate that others respond to her), *or* as N becomes large, equation 10 simplifies to the following:

$$c_{tot} = 1 + \frac{\lambda}{1-\lambda} = \frac{1}{1-\lambda}. \quad (11)$$

This reveals that, at least in the scenario in which everyone responds to everyone else's contribution equally, the influence process modeled here follows a simple multiplier pattern: Betty's initial, exogenously determined hour results in potentially large total contributions as actors iteratively react to each other's reactions. In addition, this total equilibrium contribution is, in the limit, independent of N, although individual contributions are not. The reason is that a kind of dilution occurs as the number of actors increases: With more actors, the initial volunteered contribution of any single actor is worth less because there are more people initially volunteering nothing, and this brings down the average. This is shown by the presence of N in the denominator of equation 8b. But because there are also more actors subject to the influence process, the total equilibrium contribution is unchanged: Everyone contributes less, but there are more people contributing.

If $\lambda = 1$, on the other hand, total contributions at equilibrium increase linearly with N and exponentially with ν (keeping in mind that ν is constrained to vary between 0 and 1). That is, for $\lambda = 1$,

$$c_{tot} = 1 + \frac{1}{\frac{1-v}{N+v-1}} = 1 + \frac{N+v-1}{1-v}$$
$$= \frac{N}{1-v}. \qquad (12)$$

In general, the set of equilibrium contributions given a range of values for x_i across N actors can be calculated by solving the set of N simultaneous equations corresponding to equation 3. Using matrix notation, this system of equations can be rewritten as follows:

$$c^* = \mathbf{x} + \lambda \mathbf{W}\mathbf{c}^*, \qquad (13)$$

where $\mathbf{c}^*$ and $\mathbf{x}$ are N × 1 vectors of equilibrium and initial contributions, respectively; λ is a matrix in which the diagonal elements are actor-specific discounting parameters and the off-diagonal elements are equal to 0; and $\mathbf{W}$ is an N × N matrix in which the diagonal elements are 0 and the off-diagonal elements are equal to 1/(N – 1).[9] $\mathbf{Wc}^*$ is thus an N × 1 vector in which the *i*th element gives the average equilibrium contribution for all N – 1 actors other than *i*. Solving for $\mathbf{c}^*$ gives

$$c^* = (\mathbf{I} - \lambda \mathbf{W})^{-1}\mathbf{x}, \qquad (14)$$

where $\mathbf{I}$ is an N × N identity matrix. Equation 14 thus succinctly describes the equilibrium contribution for each actor, given the values of $\mathbf{x}$ and λ.[10] Notice, for example, that if $x_1 = 1$ and $x_i = 0$ for all $i > 1$, then the first column of the N × N matrix $(\mathbf{I} - \lambda\mathbf{W})^{-1}$ gives the equilibrium contributions of each actor, i.e., c_i^* is given by the *i*th element in the first column of $(\mathbf{I} - \lambda\mathbf{W})^{-1}$. (This is because multiplying $(\mathbf{I} - \lambda\mathbf{W})^{-1}$ by a column vector with 1 in the first row and 0 in all other rows yields a column vector that equals the first column of $(\mathbf{I} - \lambda\mathbf{W})^{-1}$.) The sum of the elements in the first column of $(\mathbf{I} - \lambda\mathbf{W})^{-1}$, therefore, gives c_{tot} when actor 1 initially volunteers one hour and everyone else volunteers nothing.

But the most useful property of this model is that the elements of $\mathbf{W}$ are not required to equal 1/(N – 1). That is, equation 14 can be used to calculate equilibrium contributions even if actors assign unequal weights to the behavior of others when deciding how to alter their own behavior. As long as the rows of $\mathbf{W}$ sum to unity, i.e., as long as the N × 1 vector $\mathbf{Wc}^*$ expresses some form of actor-specific weighted average of contributions, $\mathbf{c}^*$ can be calculated from equation 14. If social ties are structured so that actors are not exposed to the behavior of everyone else, but only to a subset of relevant others, the influence process changes dramatically. The next section examines these changes in detail.

EFFECTS OF NETWORK STRUCTURE

I assume that social ties are binary and symmetrical, i.e., *i* is either tied to *j* or not, and *i* is tied to *j* if and only if *j* is also tied to *i*. The assumption of symmetry makes considerable sense given the substantive focus of the model: If *i* interacts with *j* and consequently is aware of what *j* is contributing to the collective good, it is reasonable to assume that *j* will likewise know what *i* is willing to contribute. The assumption that ties are binary is not essential, but it simplifies some of the calculations without unduly altering the substantive implications of the model. In the analysis that follows, the binary adjacency matrix that represents the pattern of symmetric ties is normalized so that the rows of $\mathbf{W}$ sum to unity.

Even with these assumptions, the number of possible network structures is extraordinarily large except for very small networks, making generalizations about structure difficult. (For a set of N ordered nodes, the number of distinct symmetric and binary networks is $2^{N(N-1)/2}$. However, the number of distinct network *struc-*

[9] Equilibrium solutions are easily calculated even when each actor has a different value for λ. In the examples investigated here, however, I assume that λ is equal for all actors except the volunteer. This permits the derivation of tractable closed-form solutions for equilibrium outcomes; moreover, these solutions represent the central tendencies for scenarios in which the values of λ are permitted to vary around a specified mean.

[10] Note the similarity between this formalism and Friedkin and Johnsen's (1990) specification of "social influence theory." In both cases, some outcome variable (y) is a function of a set of actor-specific starting values and the values of the outcome variable for other actors in the system. The central difference is that Friedkin and Johnsen use this model to predict the emergence of consensus, whereas I model contributions to a collective good. The outcome of interest in their research is *uniformity* in the equilibrium values of y, whereas in the present context the central issue is total contributions, i.e., the *sum* of the equilibrium values of y.

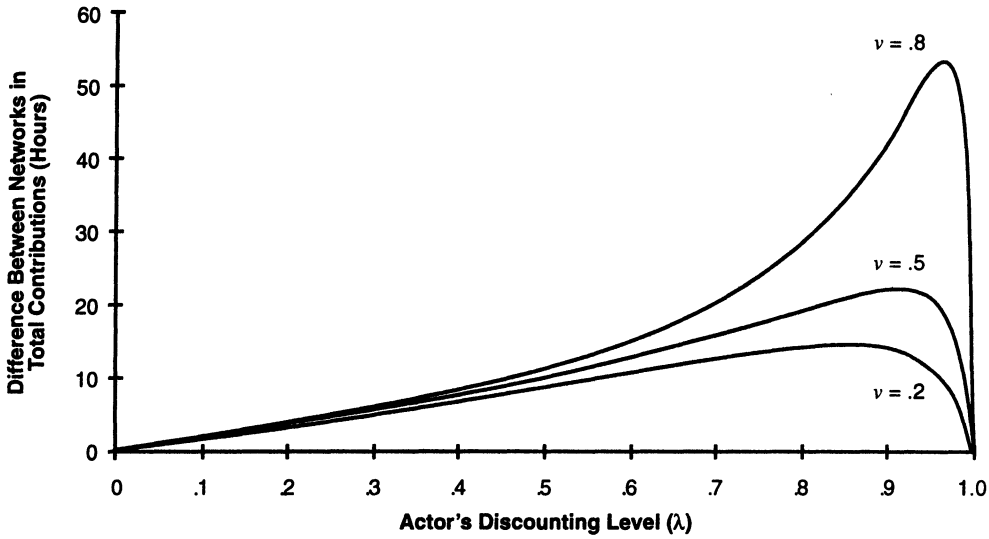

Figure 1. Difference Between Star Networks and Fully Connected Networks in Total Contributions by Actor's Discounting Level (λ)

tures is somewhat smaller because two distinct networks may be structurally isomorphic.) My purpose here is to derive a few general statements about the effects of structured social ties in networks of arbitrary size.

The best place to start is by deriving c_{tot} for certain archetypical network structures. Theoretical discussions of collective action often take for granted that, when social networks in a group are dense (when density is defined as the ratio of existing ties to possible ties), people in the group will contribute heavily to collective goods. Discussing workers in two hypothetical communities, Alpha and Beta, of which the former is close-knit and the latter atomized, Marwell et al. (1988, p. 505) stated that "we would find virtual unanimity among sociologists in predicting that the employees in Alpha are more likely than those in Beta to act collectively." However, Marwell et al. called attention to the competing influence of network centralization, while Macy (1991a) suggested that sparse networks may provide better opportunities for cooperative behavior by reducing the likelihood that random defections will spread through the group. Similarly, the model outlined here indicates that the network considered in the previous section — a network with maximum density because everyone is tied to everyone else — yields, at least in some situations, a distinctly mediocre level of collective good production. On the other hand, the model shows that this effect may depend on the structural location of the volunteer.

Consider the case of the polar opposite of the completely connected network: a minimally dense network, i.e., a network with the minimum number of ties necessary for every node to be "reachable" by some path from every other node. For a network with N actors, this minimum number of ties is N – 1; N nodes are mutually reachable if they are linked by N – 1 ties into a "chain" or a "star."

For all possible networks of size N in which only actor 1 offers a one-hour initial contribution, and for any value of λ or v, the network that results in the maximum equilibrium contribution is a "star" with actor 1 at its center. The reason is simple. First, the influence of actor 1's initial contribution on any actor i is greater for shorter network paths between actor 1 and actor i; this results from the fact that $\lambda < 1$, which attenuates the impact of actor 1's volunteered contribution at each step in the chain of influence. Second, the impact of the volunteered contribution on actor i is greater the fewer the ties i has to other actors (recall the "dilution" effect discussed earlier). A star-graph links every actor to actor 1 through a path of length 1, the shortest possible path. Because no actor is tied to anyone other than actor 1, the effect of actor 1's volunteered contribution is unmitigated by links to others who have not volunteered.

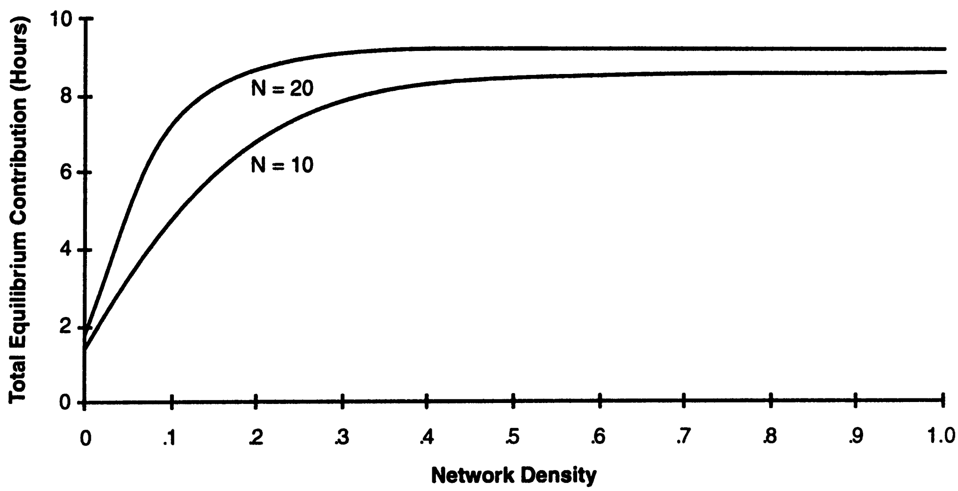

Figure 2. Total Contributions by Network Density: Networks With Random Actor Volunteering One Hour

Solving equation 14 for a star-shaped network in which the central actor initially volunteers to contribute one hour gives a total equilibrium contribution of

$$c_{tot} = \frac{(N-1)\lambda+1}{1-\nu\lambda^2}. \quad (15)$$

So, if $\lambda = .9$, N = 20, and $\nu = .5$, then $c_{tot} =$ [19(.9) + 1]/.595 = 30.42. This total contribution, which (by definition of a "star" of size 20) occurs in a network with density .1 (density is the number of existing ties divided by N[N – 1]/2), is four times greater than the equilibrium contribution based on a fully connected network, which by definition has a density of 1. Figure 1 plots the difference in total contributions yielded by these two network structures against values of λ for three different levels of volunteer responsiveness (ν). For low values of λ, the advantage accruing to centralization is more or less independent of whether or not the single volunteer echoes the reactions of others by adding to his or her unconditional contribution. But for $\lambda > .5$, the differences start to increase sharply for the scenario in which enthusiasm at the collective effort induces the volunteer to raise the stakes still further. As λ approaches unity, however, the large advantage of the star network begins to evaporate. Indeed, when $\lambda = 1$, equation 15 gives the same level of total contributions as equation 10; for both network structures, total contributions simplify to N/(1 – ν).

These findings clearly indicate that, when actors peg their contributions to the contributions they observe among their social contacts, network density can be deleterious to collective action to varying degrees — depending on the rate at which normative pressure and enthusiasm about the prospects for success prompt actors to emulate the contributions of others. Moreover, the size of this effect depends on the degree to which volunteers in turn respond to nonvolunteers. But this leads to two further questions. First, are these effects of network structure contingent on the network position of volunteers, as the sensitivity of c_{tot} to ν suggests? Second, do these effects hold for "messier" network structures? Figures 2 through 4 show the overall relationship between network density and total contributions for situations in which one actor volunteers an initial one-hour contribution. For each density level between 0 and 1 at intervals of .01, 500 networks were sampled from the universe of possible networks and equation 14 was calculated in each case to give the total contribution for each sampled network. The graphs show the average total equilibrium contribution by density for these sampled networks for three volunteer scenarios: The volunteer is randomly selected (Figure 2); the volunteer is always the most central actor in terms of the total number of ties to other actors (Figures 3a and 3b); the volunteer is always the least central actor in the network (Figure 4). Figures 2, 3a, and 3b present results for networks of varying sizes

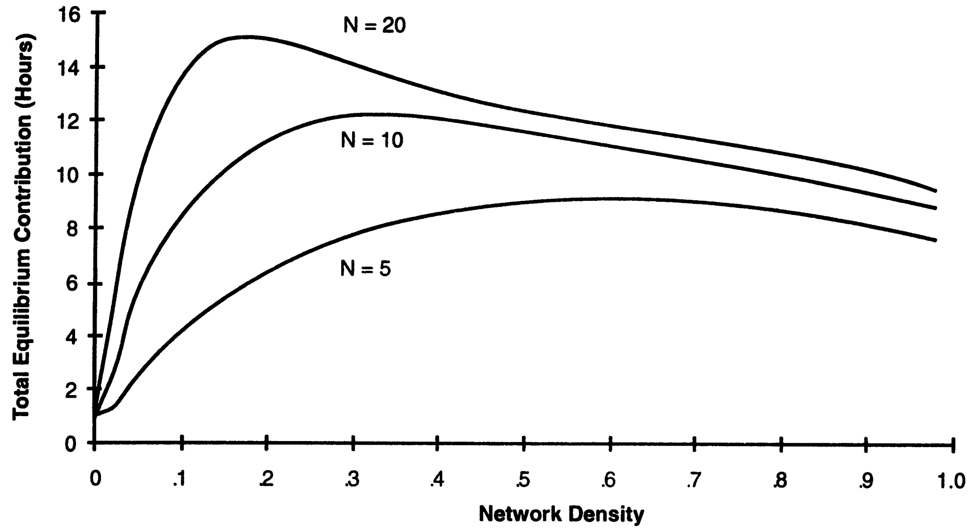

Figure 3a. Total Equilibrium Contribution by Network Density: Networks With Most Central Actor Volunteering One Hour ($\lambda = .9$, $\nu = .8$)

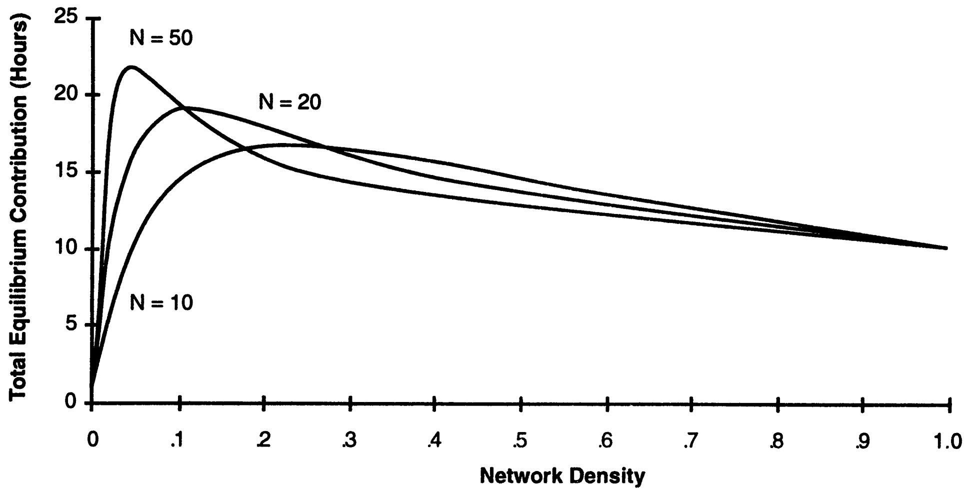

Figure 3b. Total Equilibrium Contribution by Network Density: Networks With Most Central Actor Volunteering One Hour ($\lambda = .9$, $\nu = 1$)

(results for the last scenario are more or less independent of network size). In all figures except 3b, $\lambda = .9$ and $\nu = .8$; Figure 3b depicts results for $\nu = 1$. In the scenarios represented in Figures 2 and 4, low values of the two parameters produce low total contributions, but the patterns are the same. Even when $\nu = 0$, i.e., when volunteers hold steady at their initial contribution levels, the effects of network structure are still noticeable.

Clearly, density has a radically different effect on total contributions depending on the structural position of the actor who makes the initial unconditional contribution. If the volunteer is simply a randomly selected actor (Figure 2), total contributions increase steadily with density, but level off at a little under 10 hours once density reaches .5, or in other words when half of the possible pairs of actors are tied. In this scenario, then, additional ties are useful up to a point, but then make no difference; if the volunteer is an "average" actor in terms of the number of others to whom he or she is tied, then total contributions are no greater in extremely dense networks than in moderately dense ones.

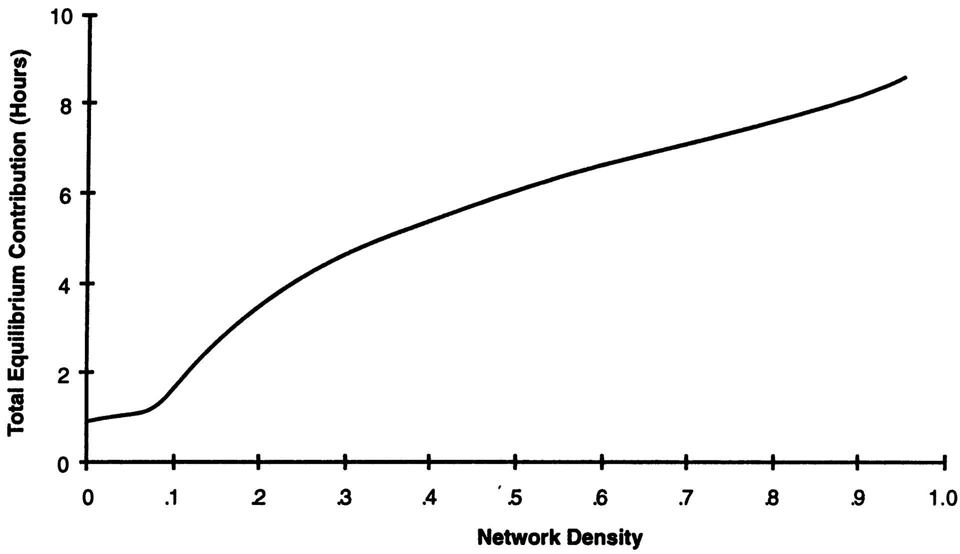

Figure 4. Total Equilibrium Contribution by Network Density: Networks with Least Central Actor Volunteering One Hour

On the other hand, when the initial contribution is made by the actor with the most ties (Figures 3a and 3b), more ties mean *lower* total contributions except when networks are so sparse that some actors are completely isolated. That is, once there are enough ties to ensure that most actors are tied to someone, additional ties serve only to dilute the effect of the central actor's volunteered contribution. Consequently, sparse networks provide the highest level of contributions in situations in which the most central actor is the volunteer. Moreover, Figure 3a shows that this effect is even stronger for large networks: With more actors, total contributions are larger and the point at which new ties start hindering rather than aiding contributions occurs at lower densities. When v = 1 (Figure 3b), network size actually has a *negative* effect on contributions at high densities. However, the near convergence of the three lines in Figure 3a at the highest density levels, and their actual convergence in Figure 3b, show that the effect of size disappears as network density approaches 1. The explanation for these findings again rests on the notion of dilution: For dense networks, the presence of more actors means that everyone is tied to more people who do not volunteer anything, reducing the impact of the one actor who volunteers an hour. In sparse networks, the presence of more people does not on average have this effect because of the greater likelihood that additional actors are tied only to the central volunteer. Consequently, more actors means there are more people subject to the influence of the volunteer rather than more people bringing down the average expected contribution. This advantage disappears, of course, when high density guarantees that everyone is tied to nearly everyone else.

When the least central actor is the volunteer (Figure 4), density has a monotonically *positive* effect on total contributions. In this case, adding ties helps because, even in networks in which every actor is mutually reachable by every other, the least central actor will on average be linked to other actors by longer paths. This means that the impact of that actor's volunteered hour will be reduced not only by the presence of nonvolunteers, but also by the greater number of steps it takes to reach everyone else. If, to expand the cast of characters, Betty is the least central actor because she is tied only to Frank, then every other actor will be influenced only by the effect of Betty's contribution on Frank. Since λ is less than unity, the added step required for the influence process to reach the other N – 2 actors has a cost in terms of the discounting reflected in the value of λ. And because new ties will, on average, reduce the length of paths to Betty, they will increase the influence of her volunteered contribution until everyone is directly connected to everyone else.

Finally, in all three scenarios, networks with a high degree of intransitivity (i.e., networks in which an *i-j* tie and a *j-k* tie imply that there is no tie between *i* and *k*) will be conducive to greater total contributions, though this effect will be smaller for denser networks. In groups in which ties are sparse, a tendency toward intransitivity will produce connected networks, whereas transitivity will divide networks into cliques that are isolated from each other (Davis 1967). As a result, intransitivity will expose more actors (either directly or indirectly) to the influence of one actor's volunteered contribution, generating higher levels of contribution at equilibrium. This effect, too, will vanish in dense networks, as the increasing number of ties guarantees that everyone will be connected by some path to everyone else.

DISCUSSION

I have attempted to derive predictions about contributions to collective goods using a formal model that shares several features with the recent work of Marwell et al. (1988), Oliver and Marwell (1988), and Macy (1991a, 1991b). A key element of these models is the assumption that actors make decisions about contributing to collective goods interdependently. Moreover, it is assumed that networks of social relations provide the apparatus through which actors influence each other's behavior. I have tried to improve on this past work by proposing a formalism that yields predictions through analysis rather than computer simulation. Given a network structure and a range of values for volunteered contributions, my model permits exact calculations of equilibrium levels of contribution. This property of the model helps to identify relationships between model parameters and collective action outcomes with greater precision than is possible with simulation results; in particular, analytic solutions ensure that arbitrarily small changes in parameter values will not lead to unknown changes in predicted outcomes.

On a substantive front, the behavioral mechanism I use differs from those of previous authors in that it explicitly incorporates both a pragmatic and a normative component: Actors are motivated by a concern for efficacy and by a fairness norm. In my model, therefore, decisions about contributing are not determined solely by utility maximization, nor are they the result of operant conditioning. In this sense, my theory does not "explain" prosocial behavior by reducing it to some other mechanism, as the idea of a norm to some extent presupposes prosocial behavior. Rather, my purpose has been to explore the impact of network structure on collective action, *taking for granted* that individuals are guided by a norm of fairness.

Several of the predictions generated by the model concur with those of other theoretical models, even though the logic underlying them is different. Above all, the connection between network centralization and collective action highlighted by Marwell et al. (1988), and the negative effect of "cliquishness" described by Macy (1991b), are echoed here. Network centralization affects total contributions because of the competing influences of volunteers and shirkers on actors trying to match the average contribution of their peers: When the volunteer is a centrally located actor, high centralization means that most actors perceive a high average level of contribution because they are tied to relatively few shirkers.

At the same time, my model suggests that these network effects are contingent on the structural position of actors who contribute voluntarily. For an actor who is centrally located in terms of "closeness," i.e., short paths to others (Freeman 1979; Bonacich 1987), volunteering will have far greater effects when the network is sparse because the impact of the volunteered contribution will not be vitiated by social exposure to nonvolunteers. But for marginal actors, volunteering will have little impact on the contributions of others unless networks are dense and centralization is commensurately lower. Earlier models have not called attention to this contingency.

A second, metatheoretical consideration leads to divergent predictions from models that explain cooperative behavior in terms of cognitive dissonance (Opp 1989), learning theory (Macy 1991a, 1991b), or bounded utility maximization (Marwell et al. 1988). Any model that assumes that the process leading to collective action occurs behind actors' backs, i.e., that actors' understanding of how collective action works is less accurate than the modeler's understanding, leads to predictions of instability if actors are permitted to reflect on the process. That is, if such a model is initially correct and actors learn that it is correct (by reading social science journals, or simply by thinking about the problem), then the collective action predicted by the model may collapse. For instance, if actors learn that their individual contributions are not really the cause of positive outcomes, or, in other words, that their past responses to positive and negative reinforcements were — on the individual level — misguided, they may revert to standard free-rider logic. In contrast, actors who "learn" that their past contributions have been guided jointly by norms and by efficacy considerations have no reason to change their behavior — the degree to which a norm is binding on an actor is not diminished by his or her awareness of it. Indeed, norm-oriented actors can be expected to resist the temptation to free-ride even if they are told that free-riding is rational, or that their past contributions have been motivated by operant conditioning.[11]

This suggests that a simple test of whether obedience to fairness norms in collective action is reducible to some other behavioral mechanism could be constructed using an experimental or quasi-experimental design comparing "knowledgeable" with "naive" actors. To the extent that actors are guided by norms, decisions to contribute to collective goods should be unaffected by insight into the process. In contrast, if actors contribute to collective goods because of a "magical belief" (Macy 1991b, p. 734) that their individual actions will have a noticeable impact, exposure to an argument to this effect should reduce total contributions. The extent to which fairness norms play an important role in collective action can be judged, therefore, from the degree to which theoretical explanation of such action corrodes contribution levels.

CONCLUSION

According to the model I have presented, properties of networks should vary widely in their effects on collective action outcomes depending on the structural positions of those who volunteer. In addition, regardless of volunteer location, network density and size are predicted to exhibit strikingly nonlinear relationships with contributions to collective goods. Both predictions indicate that it is risky to make generalizations about the impact of network structure in the absence of detailed information about collective action settings. The model outlined here, therefore, helps to make sense of the elusive character of collective action, and of the difficulty theorists have in explaining why individuals end up doing apparently irrational things with collectively rational results. The solution to the puzzle lies, I argue, in the influence process I have described formally — the mechanism by which individual agency (in this case, volunteering) is routed through norms, efficacy concerns, and social structures to produce macro-outcomes that neither the actors involved nor the social scientists who study them are likely to have predicted.

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[11] Marwell and Ames (1979) reported that economics students choose the free-rider strategy more often than other students, suggesting that contributions may be sensitive to insight. But this finding may be the result of a selection effect if economics majors are disproportionately scornful of fairness norms.

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