LEARNING THEORY AND THE LOGIC OF CRITICAL MASS*

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The Oliver-Marwell theory of "critical mass" is a prominent solution to the "free-rider" problem that plagues collective action in large groups. I reformulate the theory as a stochastic learning model in which cooperative responses are shaped by the social sanctions and cues generated by the responses of others. This relaxes four assumptions in the original formulation: that the actors are rational, decisions are isolated events, outcomes are deterministic, and public goods have pure jointness of supply and "collective profit." Computer simulations then show how adaptive actors become trapped in a suboptimal equilibrium and how they escape through attainment of critical mass. "Start-up" problems arise from accommodation to social costs and not from low returns to early contributors as previously believed. Simulations also identify a new dilemma of group size and show why solidarity tends to emerge in response to crisis. Finally, normative solidarity appears to be a consequence rather than cause of critical mass but may promote recovery from random deviance.

The theory of "critical mass"[1] proposed by Oliver, Marwell, and their associates (Oliver, Marwell, and Teixeira 1985; Oliver and Marwell 1988; Marwell, Oliver, and Prahl 1988), addresses a fundamental problem of collective action. The instrumental pursuit of collective gain can lead members of an interest group into a "social trap" (Platt 1973) in which the group suffers from what Hardin (1982, p. 6) calls "the back of the invisible hand." The trap has two jaws, the free-rider problem and the problem of efficacy. The free-rider problem is that an individual member of the group can benefit even if she does not contribute. The efficacy problem is that she may not benefit even if she does contribute. Free-riding is possible because public goods are not excludable (benefits cannot be made contingent upon contribution). The efficacy problem is created by the pooling of contributions such that "only a fraction of the benefits of one person's action accrues to that person" (Coleman 1987, p. 59).

Olson illustrates the two problems. "The rational individual in the economic system does not curtail his spending to prevent inflation . . . because he knows, first, that his own efforts would not have a noticeable effect, and second, that he would get the benefits of any price stability that others achieved in any case. For the same two reasons, the rational individual in a socio-political context will not be willing to make any sacrifices to achieve the objectives he shares with others" (1965, p. 166). Hence, commuters are generally unwilling to pay the cost of converting their cars to burn propane or to suffer the inconvenience of public transportation, and those who do are not acting rationally, even as all choke on congested freeways.

Since Olson's (1965) classic study, rational choice theorists have generally concurred that collective action requires "selective incentives" that detour the free-rider problem by providing additional benefits that are conditional upon individual contributions. Collective action, in other words, occurs only as a by-product of conventional market behavior — investment in private, excludable goods. Analysts are thus led to search for the hidden agenda that motivates rational actors to contribute to a common cause.

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[1] As the authors note, "critical mass" has been used metaphorically in the social movement literature for many years; e.g., the newsletter of the Collective Behavior and Social Movement section of the American Sociological Association is titled *Critical Mass Bulletin* (Oliver et al. 1985, p. 523). Their work formalizes the concept and demonstrates its theoretical moment.

For example, unions may obtain higher wages for free-riders, but they provide pension plans, health benefits, and grievance procedures only to dues-paying members (Olson 1965). Similarly, approbation, promotion, and status are more likely to be conferred on dedicated than on feckless members of the group, as illustrated by Coleman's (1987) account of the "rational zealot."

The Oliver-Marwell experiments break with the selective incentives approach. They show how collective action need not be a mere spinoff from the pursuit of private goods but can be successfully mobilized through direct appeals to a common interest. Building on Hardin's (1982) work, the Oliver-Marwell group springs the trap by solving the efficacy problem, which then makes free-riding innocuous. Public goods, they point out, are not only nonexcludable, they also tend to have "jointness of supply." Pure jointness means that the cost of the public goods does not increase with the size of the group that consumes them. The classic illustration is the lighthouse that costs the same no matter how many benefit, and "one person's consumption of it does not reduce the amount available to anyone else" (Hardin 1982, p. 17).

This generates an important result. Where free-riders are not a burden on those who contribute, it is not necessary to organize every member of a large interest group. A small subset or "critical mass" of "highly resourceful and interested members" can patronize a much larger group without concern that the benefit to others will diminish their own. They give as examples the good citizen who phones in to report a power outage, or the user who purchases computer software that is then made available to everyone on the system since this does not reduce its utility to those who paid for it (Oliver and Marwell 1988, p. 3).

In groups with resource inequality, the requisite number of volunteers may be quite small. The concentration of interests and resources solves the efficacy problem created by "small, isolated contributions," and thus "explains why most action comes from a relatively small number of participants who make such big contributions to the cause that they know (or think they know) they can 'make a difference'" (Oliver and Marwell 1988, p. 7).

In sum, the theory of critical mass provides a compelling solution to the efficacy problem, showing that investments in public goods can be highly cost-effective no matter how large the number of noncontributors. This is a much needed corrective to the prevailing belief that free-riding makes contribution pointless in large groups.

A STOCHASTIC LEARNING MODEL OF CRITICAL MASS

This study extends the theory of critical mass by relaxing four strong constraints in the original formulation: (1) that the actors are rational, (2) that decisions are isolated events, (3) that outcomes are deterministic, and (4) that public goods have pure jointness of supply and "collective profit."

Learning and Rationality

The theory of critical mass entails the conventional rational choice assumption that actors with limited resources seek to "spend wisely" based on estimates of cost-effectiveness (Oliver and Marwell 1988, p. 2). The authors do not claim that actors are always fully rational; they only seek to demonstrate what might happen if they were (1988, p. 2). While this is a useful exercise, their model may have limited applicability to cooperation in everyday life, as they are careful to emphasize. Calculations of cost-effectiveness are clearly relevant to collective action among entrepreneurs, legislators, union negotiators, military strategists, and seasoned community activists. However, not all members of interest groups have the disposition, information, or analytic skill to assess the marginal impact of their investment in public goods.

This is not to say that the costs and benefits of participation do not matter for collective action to succeed. On the contrary, the task is to show how they do, even when the consequences are unintended. Recent applications of social learning theory to the emergence of symbiotic exchange (Macy 1989, forthcoming) suggest an alternative formulation of the theory of critical mass that addresses this task. The proposed behavioral model retains the core rational choice assumption that the costs and benefits of collective action condition the choices of the actors. However, we need not assume that this occurs via the estimated rate of return on investments in public goods.

Suppose instead that the outcomes of social interaction operate as positive and negative sanctions or social cues that guide actors toward anomie or solidarity through a process of stochastic search, based on reinforcement and attenuation of cooperative propensities. For example, members of a village may regularly contribute time to a community garden which benefits all who stroll through the commons. If there is sufficient commitment, collaborative efforts may produce striking results and contributors will feel encouraged by their accomplishments. The problem, of course, is that the bounty may also encourage free-riders to take the garden for granted. In an anomic community, on the other hand, the village green may deteriorate sufficiently to induce rejuvenating efforts, but volunteers will eventually lose heart unless they become a critical mass. In short, as the level of individual and community involvement changes, so too do the signals received by each member, which in turn modify each member's propensity to contribute.

This model of stochastic learning extends the theory of critical mass in three ways: (1) It greatly reduces the cognitive demands on the actors; (2) it applies to behavior based on normative as well as instrumental concerns; and (3) it applies to situations where rational actors may be trapped by strategic "gaming."

1) Cognitive demands. The rational choice formulation requires "forward-looking" actors who are able to compute the expected rate of return on investments in public goods. This is a challenging task, requiring knowledge of the jointness of supply, the distribution of resources and interests within the group, current and expected levels of contribution by others, and the shape of the production function (showing the profitable region after start-up costs have been paid and before additional contributions become largely redundant). Even for market actors, marginal utility calculations can place "extremely severe strain on information-gathering and computing abilities" (Arrow 1986, p. 213). Hence, these demanding calculations seem unlikely to inform the typical volunteer.[2]

Stochastic search does not require members of interest groups to have either the disposition or capacity to forecast the rate of return. Our "backward-looking" pragmatists may be just as self-interested, just as concerned that their efforts are worthwhile, and just as worried about the future, but they use a much simpler test: They tend to repeat choices that seem to pay and avoid those that prove costly. They look ahead by holding a mirror to the past. To use a metaphor from cybernetics, they pursue their target relentlessly but cannot know its trajectory and therefore cannot intercept it by plotting a shortcut, a higher-order process that requires the capacity to anticipate future moves by the target. [For a fuller discussion of the cybernetic distinction between adaptive and rational action, see Elster's "globally maximizing machine" (1979, pp. 9-18).]

2) Normative solidarity. Although learning theory can be used to model consciously instrumental (but backward-looking) behavior, it is typically applied to behavior that is unthinking or habitual. Unlike rational choice, learning theory does not impose any assumptions about the capacity for reflective thought, much less utilitarian calculation. Adaptive responses need not be pragmatic but may instead be rule-governed, with outcomes that sanction the legitimacy of the rule. Social learning theory thus extends the scope of critical mass to those who feel their efforts are worthwhile based on normative rather than instrumental tests.

Normative solidarity differs from instrumental behavior in that the contribution to public goods is "an end in itself, regardless of its status as a means to any other end" (Parsons 1968, p. 75n). Scott's (1971) theory of moral commitment is perhaps the most fully elaborated application of social learning theory to the "internalization of norms." The attachment to prosocial norms increases when those who comply are repeatedly rewarded and when those who disregard social obligations and disdain collective welfare are penalized. Conversely, the attachment declines when compliance is penalized and deviance is rewarded. The benefits of cooperation and the costliness of privatism thus strengthen compliance, while efforts that merely reward the indolent will eventually induce a change of heart. These normative orientations may then be generalized to other social contexts, such that strong political and civil associations serve as what Tocqueville called workshops in "the art of association," providing "a thousand continual reminders to every citizen that he lives in society . . . that it is the duty as well as the interest of men to be useful to their fellows" (Tocqueville [1835] 1969, p. 512).

Scott builds on Homans' behavioral model of social exchange (1961, p. 35) in which "the behavior of one organism serves as a stimulus for

[2] Contrary to behavioral critics of economic models, private goods do not usually require the assumption that market actors are rationally motivated, only that they eventually end up acting as if they were through evolutionary and psychological processes of adaptation (Winter 1986, p. 244). Unfortunately for sociologists, this "as if" principle does not generally apply to public goods, a problem elaborated briefly in the Appendix.

the behavior of another . . . (which) in turn serves as a stimulus for the first" (Scott 1971, p. 64). In *N*-way social interactions, this mutual conditioning can generate patterns with varying degrees of regularity. Inconsistent sanctions lead to a cognitive response (based on expedience) that decays quickly. Over time, however, a consistent pattern of sanctioning routinizes habitual responses that then require only periodic maintenance. The distinction between pragmatic and normative learning thus refers not to the subjective intentions of the actor but to the persistence of the learned behavior "at a spatial or temporal remove from its sanctions" (1971, pp. 88, 107).

Where rules and obligations are explicit, compliance may tend to be unthinking and habitual, with no need to weigh the probable costs and benefits. Generic rules may require somewhat more deliberation, but the tests remain noninstrumental. For example, "what-if-everyone-acted-that-way" tests a decision against its counterfactual consequences; the behavior is not intended as a model for others but rather expresses an internalized obligation to examine choices from the standpoint of the group.

A recent cross-national study of participation in political protest is suggestive (Opp 1989). Opp finds that volunteers tend to believe their efforts can make a difference, but this appears to be largely a by-product of their "strong attachment to political protest" (1989, p. 236). Participants typically ignore the real marginal impact of their individual effort and instead act as they would have others act to attain corporate goals. For example, when confronted with the argument that "a single protester would not make any difference," German antinuclear participants responded to the effect that "if everybody thought so, there would be no protest" (1989, p. 236).

Social learning theory shows that it need not matter whether the individual's efforts can make a difference so long as the group in which they participate does.[3] Propinquity replaces causality as the link between effort and attainment. Successful mobilization reinforces the associated participation, even if a given contribution is largely redundant. Hence, the enthusiasm for participation reflects the experience of *collective* rather than *personal* efficacy.

3) "Let George do it." Social learning theory is useful for understanding how critical mass might arise in situations where strategic actors are stymied by "gaming." The rational choice solution is best suited to heterogeneous groups where the number of likely contributors is sufficiently small that a critical mass can be persuaded "If you don't do it, nobody else will," as Oliver titles a 1984 paper.[4] Otherwise, fully rational actors may be "motivated to appear less interested than they really are, and strategic gaming and misleading statements about one's interests may result" (Oliver et al. 1985, p. 548).

Group heterogeneity is the basis of an important principle of collective action that Oliver and Marwell call "the paradox of group size" (1988, pp. 4-5). Where public goods have jointness of supply, *the larger the size of a heterogeneous group, the smaller the size of the critical mass and the greater the probability that it will form.* The probability of extreme values in the distribution of resources increases with group size, reducing the minimum number of volunteers needed to attain critical mass. The problem is that a larger group also increases the number of permutations by which a critical mass of varying size might be attained. Hence we derive the free-rider corollary: the larger the size of a heterogeneous group, the larger the number of potential benefactors and *the smaller the probability that those who step forward acted rationally.*

The problem is the temptation to "let George do it." While cost-effectiveness (or net gain) is a necessary condition for rational investment in all

[3] Opp's behavioral interpretation is that participants minimize cognitive dissonance by altering their perceptions of personal efficacy to conform to their interest in the efficacy of protest. Opp's particular version of "rational choice," in which benefits need not be material, motives need not be egoistic, utility need not be calculated, and perceptions need not be realistic (1989, pp. 9-11) allows him to interpret the reduction of cognitive dissonance as utility-maximizing behavior (1989, pp. 235-7). Intention is one of the conventional criteria for rationality that Opp does not abandon. Yet it is doubtful that the reduction of psychic distress is the *intended* object of the actors. Learning theory avoids the need to assume purposive goal-attainment and is therefore better suited to the explanation of unintended consequences.

[4] The problem, of course, is that the benefactors may no longer care! Public goods that would be highly attractive when the cost is widely distributed may give pause to an elite who must shoulder the cost alone. More formally, holding group size constant, heterogeneity counteracts the effect of jointness of supply; although total costs remain constant, individual costs increase with the number of noncontributors. The problem can be solved with the additional assumption that the most resourceful members of the group also have the strongest interest in the public goods. As Oliver et al. point out, the opposite is often the case (1985, p. 543).

goods, public or private, it is a sufficient condition only for goods that are excludable. For those that are not excludable, there is no bargain like getting something for free. Even when benefits to volunteers outweigh the costs, returns must be discounted by the probability that others will step forward and pay the costs instead. Moreover, not only do rational egoists prefer to ride free, they also know that *by volunteering they alter everyone else's expectations of their behavior in future rounds*, making it less likely that others will contribute next time.

Of course, not everybody thinks like this, as Oliver et al. emphasize, particularly "in the social and political sphere" (1985, p. 548). Certainly, "backward-looking" adaptive behavior is less susceptible to strategic gaming. But anyone sufficiently tough-minded to cipher production functions and jointness of supply will undoubtedly notice the free-rider implications of nonexcludable benefits.

To sum up, social learning theory promises to provide a broader behavioral foundation for the theory of critical mass. The model of stochastic search relaxes the cognitive demands on the actors and applies equally well to both pragmatic and normative solidarity. It explains how actors might develop habits of compliance with internalized norms that lead them to volunteer without instrumental or purposive reflection and without concern that they might have held out for a better deal or that their actions might lead others to rely on them in the future.

Serial Decisions, Uncertainty, and Social Leverage

The substitution of adaptive for fully rational behavior entails relaxation of three additional assumptions: that events are discrete, processes are deterministic, and public goods are both pure and collectively profitable. First, stochastic search posits an ongoing process of decision, feedback, and course-correction. In contrast, Oliver and Marwell assume that each member is influenced by the previous choices of other actors in the course of a discrete group decision, yet each is curiously indifferent to the choices of others in previous outcomes. Each collective action is an isolated event, unrelated to previous actions and with no bearing on the future. This may sometimes be the case. However, social dilemmas seem more likely to arise in ongoing relationships in which the behavior of the actors is conditioned by the outcomes of previous interactions (including those in other groups). Members of a community, congregation, club, or political group are repeatedly confronted with the obligation to serve, as well as the temptation to take advantage of the social responsibility of others: Do I drop my gum wrapper this time, go to tonight's meeting, volunteer for tomorrow's task, or return yesterday's favor?

Of course, rational choice theory is fully capable of modeling serial choices in which actors forecast long-term effects and discount returns accordingly. However, actors who lack the information, disposition, or analytic skill to make these forward-looking calculations must chart their course on the fly. If they choose to participate, it may be because they have learned through experience that it pays to volunteer or because they have internalized solidaristic norms through reinforcement of prosocial behavior.

Second, the rational choice formulation of critical mass is deterministic; choices are fully predictable from the inputs to the model. Stochastic search introduces an element of uncertainty or "noise" that captures the idiosyncrasies of human behavior. This allowance for whim helps forgive the excessive frugality of the behavioral axioms. The model assumes only that the actors have a *tendency* to volunteer; they remain free to do the unexpected so long as their whims are randomly distributed. Note that random does not mean trivial; these idiosyncrasies turn out to be pivotal for achieving critical mass, as demonstrated below.

Finally, the Oliver-Marwell model assumes that collaboration produces nonexcludable public goods with pure jointness of supply. Hence, each member's enjoyment of the fruits of group effort does not depend on their level of resource-contribution nor on the number of others with whom the benefits are jointly consumed. Pure jointness gives groups the potential to magnify the capacities of members far beyond what they could accomplish acting alone. Public works that would be uneconomic for individuals to secure privately can thus provide ample benefits for a per capita contribution that decreases with group size. What makes collective action so appealing is precisely this "social leverage" that can be obtained through collaboration with others. The larger the group of contributors, the greater the advantage.

Although most public goods are entirely nonexcludable, it is rare that they have pure jointness of supply (Hardin 1982, p. 17). On the other hand, goods with zero jointness of supply are typically excludable from free-riders. In short, "most real cases lie between the extremes of pure and no jointness of supply" (Oliver and Marwell 1988, p. 4), as assumed in this study.

The Oliver-Marwell simulations also assume that any actor choosing between the public good and the total bundle of private contributions required to produce it would choose the former. This "collective profit" attenuates the social dilemma. As the cost of the public good declines relative to its utility, the free-rider problem disappears: The rate of return to volunteers approaches that enjoyed by everyone else. Collective action theory is preoccupied, however, with understanding why people volunteer when they are better off riding free. Hence, it is not useful to arbitrarily reduce the differential; better to assume that public goods are a "bargain," not because the average member happens to prefer them to the total resources that the group must expend to get them, but solely because of the social leverage that can be obtained on individual efforts through collaboration with others. If critical mass can be attained with these relatively low-yield investments, the result should be robust under less conservative assumptions about collective profit and jointness of supply.

To sum up, this study relaxes four simplifying assumptions in the theory of critical mass as originally formulated: calculated instrumental behavior, isolated events, deterministic outcomes, and public goods with pure jointness and collective profit. While this promises to extend the analytic (if not empirical) reach of the theory, no claim is made that actors are always adaptive in their behavior. The point of this inquiry is only to show what happens when they are. Nor is the claim that backward-looking actors necessarily learn to volunteer more readily than do confirmed utilitarians. Learning theory does not resolve the social dilemma, it only reframes it: *Where the reward to volunteers depends in part on the amount that others contribute, and where the costs to free-riders are always less than the costs to volunteers, how can penalty-aversive, reward-seeking actors learn to avoid the "back of the invisible hand"?*

A stochastic learning model of collective action identifies a possible solution. Computer simulations reveal that the social trap is a stable noncooperative equilibrium into which adaptive individuals are likely to gravitate. The simulations then show how they can escape. Those who respond quickly, without having to wait for long-term cumulative effects, can escape equilibrium by stochastic synchronization, leading to formation of a critical mass. Once critical mass is attained, social fusion becomes self-sustaining. The simulations indicate that the key to critical mass is neither group size nor heterogeneity but a decisive and aversive reaction to the social costs of unrestrained privatism, as might be expected in times of crisis. They also suggest how cooperative norms might be internalized, helping to sustain critical mass against the destabilizing effects of occasional deviance.

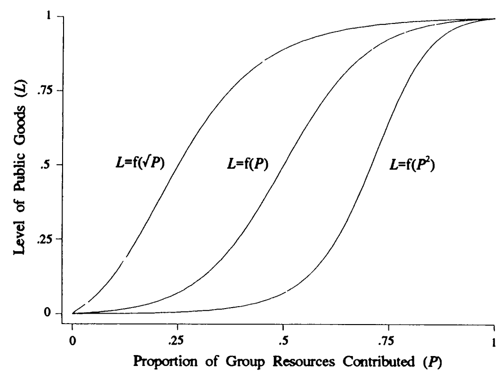

Figure 1. Level of Public Goods as a Cumulative Logistic Function of the Proportion of Group Resources Contributed

The simulation model has two major components: a production function for aggregating choices into outcomes and a learning algorithm by which outcomes modify behavioral propensities. The former is a cumulative logistic function of contributions to public goods with variable jointness of supply, and the latter is an elaboration of a conventional Bush-Mosteller stochastic learning model.

The Production Function

Following Oliver et al. (1985, p. 526), the production of public goods is modeled as a general third-order function of the total resources that members of a group choose to contribute. This production function is the familiar **S**-shaped curve depicted in the middle of Figure 1 and means that the marginal impact of contributions is initially very low but accelerates as contributions mount, creating a "bandwagon" effect. With further investment, the yield begins to level off and eventually decelerates, making contributions largely redundant toward the last. As the curve shifts to the left (see Figure 1), the bandwagon effect is dampened by increasing redundancy of effort. Conversely, as the curve shifts to the right, the bandwagon takes longer to get under way but the effect is less prone to decay.

For ease of computation, public goods can be modeled as a cumulative logistic function of the standardized level of resources that members choose to contribute to the commons, rescaled as a proportion of the total available resources and measured from the midpoint of the distribution. Let P represent the proportion of R resources that members volunteer. The level of production L is then a logistic function of P such that

$$L = \frac{1}{1 + e^{(.5 - P)M}} \tag{1}$$

where M is a slope parameter and $M \geq 1$. If $M = 1$, the function approaches linearity, while M=10 approximates a cumulative normal function and provides a suitable baseline against which variations in linearity can be explored. (M = 10 in Figure 1 and all subsequent simulations.) The inflection points can then be shifted left or right by means of nonlinear transformations of P (for example, by using $\sqrt{P}$ and P^2 respectively, as indicated in Figure 1). By design, L ranges from 0 to 1.[5] The output of public goods is then the production level L multiplied by the total resources R available to the group.

The share of this output going to each member j is given by

$$S_j = \frac{LR}{N^{(1-J)}} - C_j \tag{2}$$

where S_j represents the share of benefits received by j, net of any contribution C_j, and J is the jointness of supply. If $J = 1$, the goods have pure jointness of supply and j receives the full benefit of LR, the pooled contributions ($S_j = LR - C_j$). Hence, j's share does not depend on the size of the group. Suppose one member pays the full cost of the public goods and everyone else rides free; the patron is no worse off than if the free-riders could be excluded.

At the other extreme, if $J = 0$ (zero jointness of supply), each member receives only $1/N^{\text{th}}$ of LR, and there is nothing to be gained by contributing. Even if everyone in the group contributes an equal share, each member only breaks even. When $J = .5$, to take a midrange value, costs increase with the square root of the number served.

Each actor j's net return is their share of the public goods less their contribution C_j. Of course not all members contribute equally; hence C_j varies from 0 to R, the total resources. If $C_j = 0$, j is a free-rider and if $C_j = R$, j is a benefactor who shoulders the burden alone. To assess the effects of variability in the distribution of resources, it is useful to begin with group homogeneity. Suppose all members have one unit of equivalent resources and each must choose whether or not to contribute their share. The total units available to the group then corresponds to the number of members (R=N), and the proportion of resources contributed by the group equals the proportion of the group who choose to volunteer. We can then relax this constraint to measure the effect of resource inequality on critical mass.

As introduced in equation 2, the production function assumes that collaboration is needed to provide a collective gain, but its failure need not entail any loss. For example, parents who take pride in the quality of their local elementary school may nevertheless volunteer a weekend of labor to build a new climbing structure for the playground. Social dilemmas can also occur where symbiotic behavior is needed to mitigate mutual loss but does not provide a positive benefit. Where mutual loss is a direct result of self-serving behavior, its avoidance is a public good with low jointness of supply in that additional free-riders reduce the level of benefit obtained by a fixed level of contribution. In these cases, the theory of critical mass does not apply in either the rational choice or adaptive actor formulations. However, public harm often has some exogenous cause, and the affected parties must decide whether to forgo the enjoyment of private resources needed to mitigate the problem. For example, residents of a flood plain might be faced with the decision to help sandbag the levee after a big storm, a public good whose cost does not increase with the number of homes that are saved.

The mutual-loss model is identical to the mutual-gain model except that choices to enjoy or forgo private advantage now cumulate as social costs rather than public benefits. Hence the share (or sanction) to each member becomes

$$S_j = (1 - C_j) - \frac{R(1 - L)}{N^{(1-J)}} \tag{3}$$

[5] Note that the logistic function must be corrected by a linear operator for P = [0,1] so that corresponding L = [0,1]. The corrected algorithm is then

$$L = \frac{\dfrac{1}{1 + e^{(.5 - P)M}} - \dfrac{1}{1 + e^{.5M}}}{\dfrac{1}{1 + e^{-.5M}} - \dfrac{1}{1 + e^{.5M}}}$$

Rearranging equation 3 gives

$$S_j = \frac{LR}{N^{(1-J)}} - C_j - \frac{R}{N^{(1-J)}} + 1 \tag{4}$$

As Hardin observes, "one may often invert goods and bads, just as, with a bit of creaking in his logic, a robber with a gun might claim to be offering continued life rather than threatening quick death" (1982, p. 51). The relativity of reward is captured in a model where cooperation is needed as much to eliminate a harm as to provide a benefit. Equations 2 and 4 may then be combined as a weighted average, such that j's share is

$$S_j = \frac{LR}{N^{(1-J)}} - C_j - \left(\frac{R}{N^{(1-J)}} - 1\right)\left(\frac{1-X}{2}\right) \tag{5}$$

where $-1 \leq X \leq 1$. As X increases from -1 to 1, the sanctions go from purely negative (cooperation is less punitive) to purely positive (privatism is less rewarding). (Substituting $X = -1$ in equation 5 gives equation 4 and substituting $X = 1$ gives equation 2.) If $X = 0$, the absence of gain is as painful as the mitigation of loss is rewarding, the assumption usually made in the experimental literature.

The Learning Algorithm

The second major component of the model is the learning algorithm by which propensities to volunteer and free-ride are modified by the sanctions associated with those behaviors. The learning algorithm assumes each member j has some propensity to volunteer, p_{ij}, representing the probability that j chooses to contribute one unit ($C_{ij} = 1$) at iteration i. Each choice is determined by the magnitude of p_{ij} relative to a random number n_{ij} from a uniform distribution, such that $C_{ij} = 1$ (j volunteers at iteration i) if $p_{ij} \geq n_{ij}$ and $C_{ij} = 0$ if $p_{ij} < n_{ij}$. The choices of the actors then generate sanctions to volunteers and free-riders as given by equation 5.

These sanctions in turn modify the choice propensities, based on an algorithm that is an elaboration of a conventional Bush-Mosteller stochastic learning model for binary choice (Bush and Mosteller 1955):

$$p_{i+1} = p_i + O(1-p_i) \tag{6}$$

where p_i is the propensity to choose reinforced behavior at iteration i and O is a positive constant less than one. The reinforcement thus decays asymptotically as the propensity approaches unity.

Rapoport and Chammah (1965), Flood, Lendenmann, and Rapoport (1983), and Gardner, Corbin, and Beltramo (1984) adapt the Bush-Mosteller model to symbiotic behavior in a Prisoner's Dilemma by allowing O to vary according to the relative magnitude of the payoffs. The model can also be applied to the production of public goods by letting the reinforcement and its rate of decay vary with the costs and benefits associated with different levels of contribution. However, since O is constrained by definition to the interval $-1 < O < 1$, it is necessary to standardize the production function to conform to this constraint. Substituting $L = [0,1]$ and $C = [1,0]$ in equation 5 and simplifying gives the limiting values:[6]

$$S_{\lim} = \pm\left[\frac{R}{2N^{(1-J)}} + .5 + \left(\frac{R}{N^{(1-J)}} - 1\right)|.5X|\right] \tag{7}$$

Hence, the outcomes may be rescaled as

$$O_{ij} = \frac{ES_{ij}}{S_{\lim}} \tag{8}$$

where E represents the efficiency of the reinforcement (the number of applications needed to alter behavior) and $0 < E \leq 1$. Low efficiency might reflect a lack of interest in the outcomes, a noisy environment, or time lags that weaken the association between sanction and behavior. For example, $E = .1$ means that learning occurs at 10 percent of the possible rate — at least ten reinforcements would be required to fully convert an initially determined free-rider.

The propensity to volunteer is reinforced when prosocial behavior is rewarded ($C_{ij} = 1$ and $O_{ij} > 0$) or privatism is punished ($C_{ij} = 0$ and $O_{ij} < 0$):

$$p_{i+1,j} = p_{ij} + [O_{ij}(1-p_{ij}^{(1/|O_{ij}|)})C_{ij}] - [O_{ij}(1-p_{ij}^{(1/|O_{ij}|)})(1-C_{ij})] \tag{9}$$

[6] The standardization does not model a psychological process but simply rescales the production function to conform to the constraints of the Bush-Mosteller algorithm. There is no assumption that the actors are aware of the maximum possible collective output and weight the reinforcements accordingly. Rather, by definition, actors never have propensities that exceed unity, and the standardization is a convenient way to make the math conform.

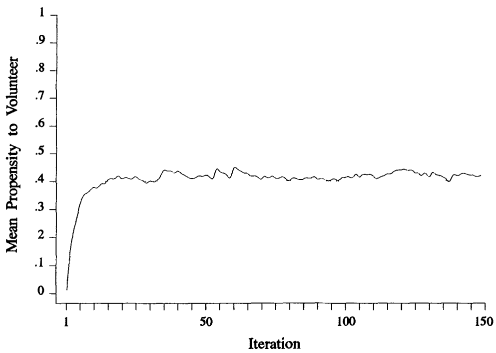

Figure 2. Social Trap as Suboptimal Equilibrium ($N = 100$, $J = .5$, $E = .1$, $X = 0$)

Since O can take on negative values, equation 6 was elaborated to allow for the reward for contribution (C) as well as the punishment for noncontribution (1-C), as indicated in equation 9 by the two adjustments to p_{ij}, one positive and the other negative. Hence, the reward for contribution is added to the propensity when $C_{ij} = 1$, while the negative sanction for privatism is subtracted when $C_{ij} = 0$, causing the propensity to volunteer to increase in either case. Conversely, if feckless behavior is rewarded or solidarity is suckered, then the propensity to free-ride (1-p) is reinforced, i.e., 1-p is substituted for p on both sides of equation 9 and 1 - C is substituted for C.

Finally, the algorithm assumes that reinforcement decays with the propensity and that the larger the stimulus, the more rapid this decay, as modeled by the exponential expression $1/|O_{ij}|$. The larger the reward, the faster the decay as the propensity increases. Hence, large rewards change behavior more than small ones, but ten applications of a small reward have greater cumulative efficiency than five applications of a reward of twofold magnitude.[7]

SIMULATION RESULTS

Computer simulations show how adaptive actors are led into a social trap and how they might escape. Figure 2 reveals that the social trap is a stable and suboptimal equilibrium into which actors tend to gravitate in response to the social sanctions and cues generated by their mutual interaction. The simulation assumes a homogeneous group of 100 members ($N > 100$ provides little improvement in reliability at a substantial computational cost) and an **S**-shaped production function. Rewards and punishments are assumed to be relative rather than absolute ($X = 0$), i.e., the absence of expected rewards can be painful and the solution of social problems can be rewarding. The simulation also assumes only partial jointness of supply ($J = .5$) and relatively low learning efficiency ($E = .1$). When $J = .5$, the cost of the public goods increases with the square root of N. With $N = 100$, the cost is thus ten times what it would be if the benefit were limited to a single individual. When $E = .1$, learning occurs at 10 percent of the possible rate. These values of J and E preclude critical mass and are thus useful for illustrating the suboptimal equilibrium in which the group remains trapped.

Equilibrium and the Threshold of Critical Mass

The trials begin with no one willing to contribute ($p_{1j} = 0$). Excessive competition immediately generates social costs that induce some members to exercise greater civic responsibility. Given the initially low productivity (with the **S**-shaped production function), these early volunteers learn that their contributions have little effect and quickly lose heart. As the crisis continues, new volunteers come forward, with contributions ratcheting upward as they are rotated among the group.

A stable equilibrium is eventually obtained at about 40 percent cooperation. Losses then average -.052 for volunteers, -.033 for free-riders, and -.041 overall, half the loss suffered when no one participates (-.082). This is sufficient to make life tolerable but far from optimal. The adaptive response has left the group only marginally better off than it would be if individuals responded rationally and no one volunteered. The social dilemma is readily apparent: *Although adaptive actors gravitate toward behavior that is more rewarding and less punitive, the learning process aggregates into an equilibrium where outcomes remain badly suboptimal — a social trap.*

The suboptimal equilibrium is consistent with the Oliver-Marwell predictions for rational actors: Collective action may fail where public goods lack pure jointness of supply. With $J = .5$, the simulations reported in Figure 2 suggest that this conclusion may hold for adaptive actors as well.

Figure 3 diagnoses the problem as the gap be-

[7] This assumption turns out to be highly robust. Fixing the exponent at unity, the Bush-Mosteller value, alters equilibria but not the dynamics or the substantive conclusions. For a more detailed discussion of the substantive implications of alternative decay functions in a simple two-person Prisoner's Dilemma, see Swistak 1990 and Macy 1990.

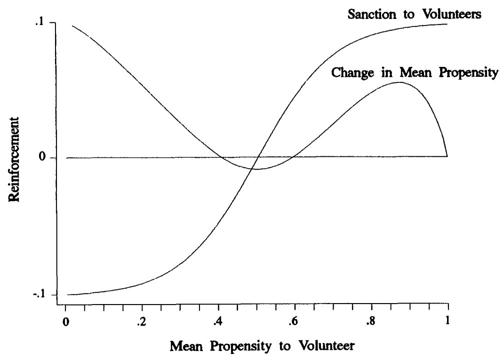

Figure 3. Equilibrium and Critical Mass (N = 100, J = .5, E = .1, X = 0)

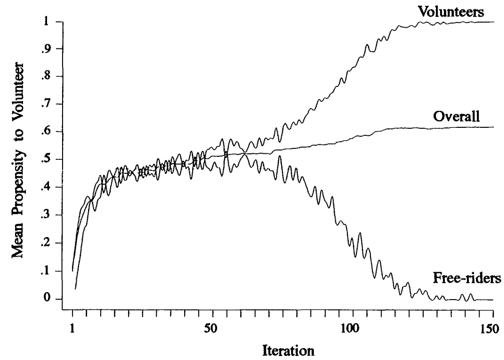

Figure 4. Critical Mass with Pure Jointness of Supply (N = 100, J = 1, E = .1, X = 0)

tween equilibrium and the threshold for critical mass (the level of contribution where investment becomes cost-effective and hence efforts become self-reinforcing). The size of the gap is a function of social leverage which, in turn, is a function of jointness of supply and group size. Figure 3 illustrates the gap for the simulation in Figure 2, plotting the change in mean propensity and the sanction to volunteers against the propensity to volunteer. Equilibria occur where the change in mean propensity crosses the abscissa, and the threshold for critical mass occurs where the sanction to volunteers crosses the abscissa.[8] There are three equilibria: a stable equilibrium at p_e = .4; an unstable equilibrium at p_e = .6; and an absorbing state (in which learning terminates) at unity. The unstable equilibrium is an artifact — the mean propensity obscures the inevitable division of the group into permanent classes of volunteers and free-riders once critical mass has been attained, as demonstrated below. For ease of presentation, "equilibrium" refers solely to the stable equilibrium. The unstable equilibrium is ignored, and the absorbing state at unity will be refereed to as "lock-in".

With J = .5 and N = 100, the equilibrium level of cooperation is 40 volunteers, while 52 members must contribute for volunteers to break even, leaving a shortfall of 12 contributors between equilibrium and critical mass. If the group could somehow get over the threshold, a critical mass might lock in self-reinforcing prosocial behavior. To do that, however, they must escape equilibrium. The group thus finds itself in a "Catch-22": In order to learn to work together, members must already know how.

[8] The threshold of critical mass can be calculated by setting S = 0 in equation 5 and solving for L and then P in equation 1.

There is a way out, however. In previous work, a stochastic learning model(of a two-person Prisoner's Dilemma showed how players can escape social traps by stochastic collusion (Macy 1989, forthcoming). The noncooperative equilibrium is stable but is not an absorbing state. Learning continues, with each player's propensity fluctuating around the balancing point. The two players will eventually synchronize their moves by chance. If the synchronization persists for several plays and the reinforcements are sufficiently large, the contestants will find themselves over the threshold. From there, the structure of interdependent outcomes pulls them inexorably into "lock-in," an absorbing state at unity.

However, the two-person game-theoretic solution has an obvious limitation. As the number of actors who must simultaneously cooperate increases, the probability that they will escape equilibrium by stochastic collusion decreases exponentially. The more moves that must be fortuitously synchronized, the longer the wait.

The work of Oliver and Marwell provides a ready solution: *It is not necessary to synchronize the actions of everyone in the group, only enough members to create a critical mass.* Figure 4 shows how the critical mass solution applies to adaptive behavior. The simulation is identical to that in Figure 2 (N = 100, E = .1) except that the public goods now have pure jointness of supply (J = 1). Figure 4 also displays the average propensity separately for those who volunteer and those who free-ride at each iteration.

With J = 1, equilibrium rises to p_e = .47 with 50 volunteers needed to make cooperation self-reinforcing, a gap of only 3 members, substantially less than the 12 additional volunteers needed in Figure 2. As the gap between equilibrium and critical mass diminishes, the probability of crossing the threshold by random fluctuation increases. (Note that the discrepancy between the rate of participation and mean propensity to volunteer is also slightly greater at $p_e = .47$ than at $p_e = .4$, the equilibrium in Figure 2.) Thus, it does not take long for the group simulated in Figure 4 to achieve critical mass (at $i = 56$).

Once this occurs, the structure of the group changes dramatically. The group splits into permanent classes of producers and exploiters as equilibrium gives way to an absorbing state (or "lock-in") in which learning terminates. Exploitation does not occur at equilibrium since the burden of supplying public goods is rotated among the membership. Once critical mass is attained, the classless interaction is replaced by a permanent system of exploitation of the many (62 percent) by the few (38 percent), but with a substantial improvement in the overall level of consumption, from an equilibrium rate of -.015 to .053 with fully entrenched classes. While the 62 percent rate of contribution is nine points below what is optimal for overall efficiency (above 71 percent, efforts become increasingly redundant), and while the exploiters do somewhat better than the producers, the improvement is clearly sufficient for what Przeworski (1985) calls "the material basis of consent." Better to be comfortably exploited than to return to a state of anomie where everyone loses equally.

The Dilemma of Group Size and Organizing Strategy

Along with jointness of supply, the Oliver-Marwell experiments identify resource inequality as a key condition facilitating formation of critical mass. For rational actors, the concentration of assets (time, money, talent) in a few hands enables highly resourceful contributors to "make a difference" and reduces the temptation to let others carry the load. Resource inequality has coincidental implications for adaptive behavior as well: *The smaller the effective subgroup, the fewer the moves that must be stochastically synchronized to spring the trap.*

The problem is that resource inequality also has an unfortunate side-effect: *the loss of the social leverage obtained by jointness of supply.* Jointness means that free riders do not increase the total cost of the public goods. Nevertheless, even with pure jointness, free-riders still increase the *individual* cost to those who volunteer. Suppose the available resources are concentrated entirely among ten of the 100 members of the group simulated in Figure 2 (or $N' = 10$). The subgroup must now contribute ten times as much for the same benefit as they would if the burden were evenly distributed.

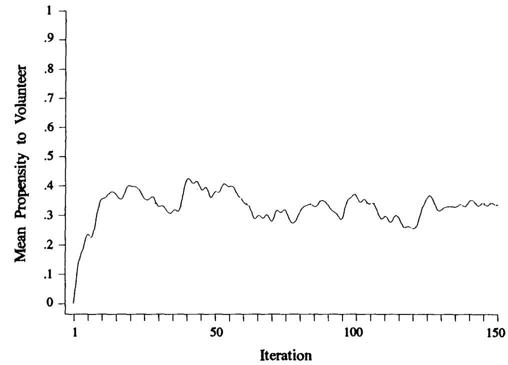

Figure 5. Failure of Critical Mass with Resource Inequlaity ($N = 100, N' = 10, J = .75, E = .1, X = 0$)

This can be offset by arbitrarily assuming $J = .75$ instead of $J = .5$. This is still short of the pure jointness assumed by Oliver and Marwell (which we know from Figure 4 leads quickly to critical mass even with $N = 100$). It also provides a convenient benchmark since it creates a condition identical to that in Figure 2 ($J = .5, N = 100$) but with a group only one-tenth as large. That is, the two changes (in resource distribution and jointness) are equivalent to a reduction in the size of a homogeneous group: The simulation with $N = 100, N' = 10$, and $J = .75$ is equivalent to $J = .5$ and $N = N' = 10$. The hypothesis is that reducing the size of the group in Figure 2 from 100 to 10 greatly increases the chances of stochastic collusion, making it much easier for the group to wander over the threshold.

Figure 5 shows that, contrary to expectations, the smaller group of potential volunteers nevertheless fails to obtain critical mass. The advantage of easier synchronization is offset by the attenuation of "strength in numbers," even though the additional burden of the indigent members is compensated for by greater jointness. All else being equal, reducing the number of volunteers whose actions must be fortuitously synchronized to escape equilibrium also reduces the reward for doing so. The lower the benefits of collaboration relative to the costs, the lower the equilibrium rate of contribution and the higher the threshold for critical mass. As a result, the core group remains trapped in a suboptimal equilibrium at $p_e = .33$ (based on the ten potential contributors), with an aggregate penalty of -.034.

The simulation illustrates the dilemma of group

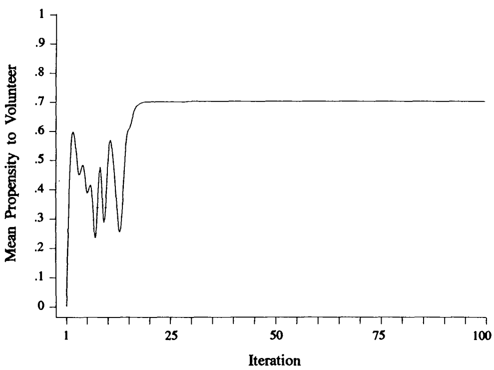

Figure 6. Critical Mass with Correlated Resources and Interest ($N = 100$, $N' = 10$, $J = .75$, $E = .1$, $X = 0$)

size: *A hard core tends to be easier to coordinate but a broader base can yield greater social leverage.* While the law of averages is more easily enforced in larger groups (making stochastic collusion less likely), this is offset by the greater leverage obtained through the multiplication of many small efforts.

Suppose that both resources and *interests* are skewed and the two distributions are positively correlated. Oliver et al. predict that this "improves the chances of there being a critical mass" since those with stronger preferences for the public goods realize that less interested members expect them to carry the load (1985, p. 543). Learning theory arrives at a similar conclusion, but here the mechanism operates behind the backs of the actors, unrelated to their vector of preferences. The greater the stake in collective action, the more salient the outcome; the more decisive the response, the fewer the moves needed to get from equilibrium to threshold, hence, the fewer the choices that need to be stochastically synchronized to attain critical mass. Collective action is thus more likely to succeed among highly interested actors whose decisive responses obviate the need for repeated applications of the sanctions over a long series of iterations.

This is corroborated in Figure 6 for a simulation identical to that in Figure 5 ($N = 100$, $N' = 10$, $J = .75$, $X = 0$), except that here the ten resourceful members are also ten times as interested in the outcomes as are the members of a homogeneous population, while the other 90 are indifferent. However, a stronger interest does not mean a greater preference for public goods. All 100 members place the same value on the public goods, relative to what they cost. They differ only in their responsiveness to the outcomes. The greater salience of the outcomes means that one-tenth the number of reinforcements are now required to convert determined free-riders into committed volunteers (E increases from .1 to 1).

In Figure 6, everyone begins with zero propensity to volunteer, generating sanctions that quickly discourage free-riding. The initially "flat" **S**-shaped production function means that free-riding remains costly as more members begin to volunteer. After only one iteration, 33 percent of the core group can be expected to cooperate, and after two iterations, those who continued to hold out have serious doubts about the wisdom of their behavior. This volatility, clearly evident in the first 15 iterations, destabilizes the equilibrium and critical mass is quickly achieved. At $i = 15$, the group splits, with 7 permanent volunteers (each rewarded .34) and 3 free-riders (rewarded .82, the same amount received by the 90 resourceless members who are unable to contribute). This is close to the optimal level of investment; with diminishing returns to scale, additional efforts would be increasingly wasteful.

For the broad range of public goods with at least moderate jointness of supply ($J \geq .5$), a critical mass will be attained almost immediately, even in very large groups, if learning is perfectly efficient ($E = 1$), i.e., if the sanctions are sufficient to alter behavior in a single application. Indeed, if interest in the outcomes is too great, the group may lock-in excessive rates of participation, with redundant contributions that lower the overall efficiency of collaboration (given the diminishing returns near the limits of capacity.)

This need for a decisive and aversive reaction to the social costs of noncooperation suggests that participation in collective action is likely to increase during periods of crisis, for two reasons: (1) Crises increase the level of interest in the outcome, and (2) crises provide a nodal point for the synchronization of responses needed to attain critical mass.[9]

These results have important implications for organizing strategies. If resources are unevenly distributed and positively correlated with interest-level, it may be useful to "concentrate organizing efforts on those individuals whose potential contributions are the largest" (Marwell et al.

[9] For example, Gamson's 1975 data provide limited historical evidence that crises promote successful collective action by protest groups. However, it is difficult to tell whether this is because of successful mobilization or because, as Gamson and others suggest, the opposition was more prone to compromise (Gamson 1990).

1988, p. 502). In other situations, the key to successful collaboration may not be to target elites but to coalesce diffuse resources into a broadly-based critical mass that maximizes social leverage.

The problem with the broad-based strategy is the greater difficulty of coordination and timing. In large groups, particularly where public goods have only partial jointness of supply, piecemeal, door-to-door organizing may be doomed by the structural dynamics of the equilibria unless coupled with the pump-priming effects of simultaneous action. Bold, effervescent mobilizations and highly dramatic symbolic appeals would seem to be indicated. The trick is to get enough of the group out of its rut (or equilibrium) to make continued participation self-reinforcing. This need for a dramatic nodal point is widely recognized among community activists. Alinsky, for example, prescribes a "final act" in which "good and evil have their dramatic confrontation" (Alinsky 1971, pp. 115-6). Groups that tend to muddle through social dilemmas may need such confrontations to jump-start broad-based involvement.

To sum up, the key to escaping social traps is the social leverage provided by "strength in numbers" and the decisiveness with which actors respond to outcomes. Resource inequality facilitates stochastic collusion but undercuts social leverage. The advantage is much greater if both resources and interest are concentrated in the same subset of actors. Where resources are dispersed, critical mass may not occur until precipitated by crisis, real or manufactured.

Normative and Pragmatic Solidarity

The need to reduce the number of choices that must be stochastically synchronized calls attention to the earlier distinction between pragmatic and normative learning. Scott's behavioral theory suggests that the internalization of norms requires a consistent pattern of sanctions over a limited but nontrivial number of applications (1971, p. 102). Nonpurposive, normative behavior is thus identical to pragmatic, expedient behavior except that *the response to changes in the signals generated by social interaction may be somewhat slower.* "When learning is established, extinction of the response by stopping the reinforcement is slow" (Boring 1950, p. 651). In short, norms are unlikely to be internalized or abandoned in a single outcome, while pragmatists may decide to change tack after every wind shift.

It follows that noncooperative equilibrium tends to be anomic due to inconsistency in the application of sanctions: Sometimes contribution pays off (depending on how many others volunteer) and at other times it does not. Hence, responses at equilibrium are more likely to be pragmatic than normative. If these pragmatic responses are also more decisive, they may in turn facilitate the stochastic collusion needed to attain critical mass.

At the same time, expediency has a downside. Even after critical mass is attained, the possibility remains that one of the volunteers will "backslide." If the critical mass is large, the defection may go unnoticed by the remaining contributors so long as their efforts continue to be reinforced. However, the reward for free-riding will not go unnoticed by the perpetrator. If the response to the reward is very strong, the willingness to volunteer may be sufficiently weakened that cheating is repeated, leading to permanent conversion. The accumulation of these defections over time could eventually cause a collapse of the critical mass.

This difficulty may be avoided by the internalization of prosocial norms once a critical mass locks in contribution. Unlike the suboptimal equilibrium, lock-in generates the consistent pattern of reinforcement needed to routinize cooperation (as well as exploitation). Habitual, unthinking compliance with corporate obligations, long a mystery to rational choice, may be hypothesized to issue from the dramatic change in the pattern of social interaction that occurs with the attainment of critical mass (the "splitting" of the group, evident in Figure 4). While such "civic virtue" may be the consequence rather than the cause of successful collaboration, once the habit is established, it is unlikely to collapse following a single betrayal. In short, *the province of normative compliance is not getting cooperation going so much as promoting recovery from occasional deviance.*

The Start-Up Problem: Accommodation to Social Costs

Start-up problems explain why many collective action opportunities fail. Oliver et al. (1985, p. 535) diagnose the problem as a rational response to the typically low yields at the outset of collective action (due, for example, to the initial expenses of organizational infrastructure). Under these conditions, calculations of marginal utility advise against being first to step forward, despite

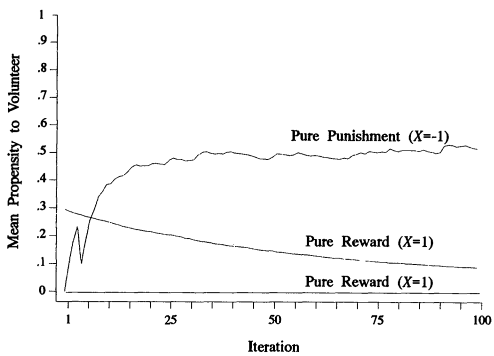

Figure 7. Start-Up and Follow-Up Problems ($N = 100$, $J = 1$, $E = .1$, $X = \pm 1$)

an interest in solving costly collective problems. Rational actors may prefer to suffer in silence rather than serve as a loss leader for the group.

Adaptive actors, in contrast, show no reluctance to take the plunge in any of the simulations, including those with only partial jointness of supply (and despite much more conservative assumptions about collective profit). The rush of volunteers during the first ten or so iterations is triggered by an aversive response to the social costs of rampant privatism. The persistence of social costs, due to the initial flatness in the production function, causes early volunteers to lose heart and others to replace them, with a net increase in the number of contributors until social costs finally begin to diminish.

Although adaptive actors respond quickly to alarms, their initial "burst of enthusiasm" soon dampens as the crisis subsides, a pattern that is precisely the opposite of the behavior Oliver et al. predict for rational actors. Once the ice is broken, they predict a bandwagon effect as yields improve. Adaptive actors not only find themselves stuck in a rut, but this equilibrium will typically obtain in the "steep" midsection of the production function, the point at which Oliver et al. expect the strongest incentives for contribution.

While Oliver et al. assume an indefinitely accelerating production function rather than an S-curve, this does not account for the different results in these simulations. As illustrated in Figure 1, the relative size of the regions of increase and decrease in marginal returns can be varied by nonlinear transformations of P, the proportion of group resources contributed. Shifting the curve to the right attenuates the effectiveness of efforts to relieve the social costs of excessive competition. Hence more widespread contributions will be forthcoming before the group settles into "muddling through." Although equilibrium obtains at a higher level as the curve shifts to the right, there is an even larger increase in the rate of contribution needed to achieve critical mass, opening a larger gap between equilibrium and threshold. The larger the gap, the lower the probability of stochastic collusion. In short, shifting the curve to the right does not pose a start-up problem, as rational choice theory predicts, *it creates a follow-up problem*: The group becomes more likely to remain trapped in a suboptimal equilibrium with just enough contribution to "get by."

Since we know that start-up problems are widespread, how are they to be accounted for if not by the poor yield to the first volunteers? Figure 7 indicates a very different diagnosis: *Failed opportunities for collective action are created by lowered expectations and accommodation to the social costs of unrestrained privatism.* With all other parameters identical to those in Figure 4 ($N = 100$, $J = 1$, $E = .1$) and a start value of zero propensity to volunteer, purely rewarding sanctions ($X = 1$) preclude the aversive outcomes that induce initial contributions. Since no one volunteers, learning terminates, creating an absorbing state at $p_e = 0$. (This will be the result for all N, J, and E.)

Even if a few members could be induced to volunteer, they will gravitate back into the equilibrium. This is illustrated in a second simulation that begins with a uniform .3 propensity to volunteer. Although contributions are always rewarding, reinforcements are larger yet for free-riders, leading to a downward slide that does not stop until the mean propensity approaches the lower limit at 0.

The absorbing state at $p_e = 0$ is an important result with notable implications for both mobilization and cooptation. Figure 7 shows how the latter may be used to undermine the opponent; a paternalistic employer who makes working conditions tolerable for unorganized workers creates an absorbing state at very low levels of solidarity that may keep the union out. Even without cooptation, a likely cause of start-up problems in collective action is that members of an interest group accommodate themselves to existing conditions such that solutions to collective problems are regarded as a comparative advantage rather than as the mitigation of costly losses. As expectations are adjusted downward over time, the absence of potential gain is no longer perceived as a loss. Social costs may acquire a sense of inevitability that reconciles group members to the status quo. In the initial stages of collective action, a key task of organizers thus becomes clear: *raise expectations.*

Once the group breaks free of the absorbing state, the organizing problem changes. Now the task is to consolidate a critical mass of volunteers by emphasizing the positive. Without positive reinforcement, critical mass cannot be attained and the group will remain in a suboptimal equilibrium or "rut." Simulations with X = -1 show that strong aversive responses induce relatively high levels of contribution, but the absence of rewards precludes formation of a critical mass, making it difficult for even committed team players to consolidate their collaboration.[10]

This "follow-up" problem means that organizers must know when to shift their emphasis from social problems and the need for change to the clear achievements of the group and the remarkable gains that have been made through collaborative effort. Once the group is in motion, "the organizer knows that his biggest job is to give the people the feeling they can do something" Alinsky notes (1971, p. 113), or as Fireman and Gamson advise, "Try to keep tangible, though perhaps small, victories coming . . ." (1979, p. 30).

This analysis of start-up and follow-up problems does not apply to rational actors. Rational choice theory does not recognize the distinction between reducing costs and increasing benefits. Citing Olson, Oliver notes in this context that "rewards and punishments do not differ and are interchangeable in their effect on individuals' rational decisions of whether to cooperate with collective action or not" (1980, p. 1361n). Lowered expectations increase the actors' appreciation of the comparative advantage of the public goods, with no net change in subjective expected utility. There is no difference between solving a costly problem and searching for "greener pastures."

In contrast, backward-looking pragmatists must successfully collude to see the comparative benefits of solidarity, but they get to experience the social costs of noncooperation by default. Hence, start-up problems will plague public goods that are useful but unnecessary while follow-up problems may be expected in response to crisis.

[10] Numerous behavioral experiments have indicated that reward is generally more efficient than punishment (Skinner 1953), but that is unrelated to the point here which is entirely a consequence of the social structure of interdependent action and has nothing to do with the psychology of the actors.

SUMMARY AND CONCLUSIONS

The Oliver-Marwell studies have advanced our understanding of collective action by showing how solidarity can thrive in large groups: Not everyone needs to be mobilized since free-riders do not necessarily reduce the benefits to those who volunteer. However, the solution is circumscribed by the assumption that symbiotic behavior issues from a rational, cost-benefit analysis. Many collective action problems arise among actors who lack the necessary temperament or information to estimate the cost-effectiveness of their contributions. The feeling that one's efforts are worthwhile may instead reflect identification with the group and its goals. Tough-minded utilitarians, on the other hand, are prone to "gaming" unless the concentration of resources and interests precludes it.

Social learning theory promises a more robust explanation of how adaptive actors might learn to avoid self-defeating competition despite the risk that socially responsible behavior may be exploited by others. The model assumes that symbiotic behavior emerges in response to the signals generated through social interaction, without the capacity or disposition for forward-looking calculation. Yet while the actors gravitate toward behavior that is more rewarding and less punitive, computer simulations show that the search process can aggregate into an equilibrium where outcomes are badly suboptimal, a social trap.

The probability of escape depends on the number of moves that must be stochastically synchronized to attain critical mass. This is a function of the size of the group (small is better), the distance that must be traversed between equilibrium propensity and the threshold for escape, and the distance covered by each move. The distance to be traversed is a function of social leverage which, in turn, is a function of jointness of supply and group size (big is better). The distance covered by each move is a function of the efficiency of the reinforcement (the level of interest in the outcome, the level of environmental noise, and the propinquity of outcomes and behavior). If the leverage obtained by symbiotic behavior and the interest in the outcomes are sufficiently strong, critical mass will be achieved regardless of the size of the group and dispersion of resources. Assuming most public goods have at least moderate jointness of supply, the key to escape from social traps is the capacity to respond decisively to social sanctions and cues, without the need for repeated applications of the sanctions over a long series of iterations.

The opposing effects of group size pose a dilemma: Small groups tend to be easier to coordinate while large groups tend to provide greater social leverage. The model thus reveals a difficulty created by resource inequality that was not apparent in the Oliver-Marwell simulations. The leverage obtained by "strength in numbers" is lost when elites patronize the masses. Hence, organizers should be wary of overreliance on a hard core. On the other hand, broad-based mobilization compromises stochastic collusion; adaptive actors may therefore need a good rabble-rouser who can rally the troops sufficiently to clear the threshold.

Organizers may also need to raise expectations; the start-up problem may be created not because actors are discouraged by the low marginal returns to initial investors but because they lower their expectations and accommodate to the social costs of unrestrained privatism. Once cooperation gains a foothold, the emphasis should be redirected to the benefits achieved through collaborative effort; e.g., organizers may need to work for a series of small victories that teach members the virtues of combination.

Finally, since the internalization of normative commitments requires a consistent pattern of reinforcement, it is more plausibly a consequence of critical mass than a cause. The pragmatic responses expected at anomic equilibrium are more conducive to escape, while the routinization of habitual compliance makes solidarity less likely to unravel in the face of random deviance.

The simulation results identify several directions for further inquiry. Elucidation of the stochastic learning model and its findings and rationale precluded discussion of empirical support. That discussion should be high on the agenda that flows from this work. The simulation results are obviously not a substitute for laboratory or field studies, and their empirical fit is compromised by the frugality of the decision algorithm. Actors are not always adaptive in their behavior, and even when they are, their actions are undoubtedly complicated by other influences. For example, learning may include imitation of the prosocial behavior of others (Rushton 1980). Moreover, participation within a range of contribution levels is more plausible than the binary choices assumed here. And expectations may be adjusted very quickly so that it is only the change in outcomes that reinforces behavior. The efficiency parameter should perhaps be allowed to vary with the consistency of the sanctions. The outcomes could also be modeled as resources as well as signals such that the distribution of resources varies and not just the propensities. Finally, the actors can learn not only to contribute to the primary goods but also to monitor, admonish, and praise other members, thus creating a second-order "selective incentive" system needed to insure a more equitable division of labor than that created by critical mass.[11] These complications represent promising directions for further experimentation and suggest the fertility of a learning-theoretic approach to social dilemmas.

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Appendix. The "As If" Principle and Public Goods

In commenting on earlier drafts of this manuscript and its predecessors, Michael Hechter and Douglas Heckathorn have repeatedly urged a more clearly specified distinction between "forward looking" and "backward looking" behavior. In light of the growing number of synthetic efforts by economists and psychologists (Cross 1983; Rachlin, Battalio, Kagel, and Green 1981), their challenge is appropriate. Does social learning theory supplant or supplement the theory of rational choice? Are rationalist and learning models rival explanations for the same set of behaviors, or do they apply to different empirical contexts, or perhaps different phases of a single optimization process?

This problem was the focus of a conference on the behavioral foundations of economic theory held at the University of Chicago in 1985. The conference papers represent the leading statements of the behavioral and rationalist positions as these unfold in direct rebuttal of one another, providing a singular opportunity for clarification of essential differences. "The stimulus for the conference," according to organizers Robin Hogarth and Melvin Reder, "was a growing body of evidence — mainly of an experimental nature — that has documented systematic departures from the dictates of rational economic behavior" (1986, p. vii). These departures, Tversky and Kahneman conclude, "are too widespread to be ignored, too systematic to be dismissed as random error, and too fundamental to be accom-

[11] Although based on rational choice assumptions, Heckathorn's model of "hypocritical cooperation" seems highly promising for reformulation as a learning-theoretic model of "second-order" public goods (Heckathorn 1989).

modated" (1986, p. 68). This experimental evidence supports the cumulative skepticism of writers like Cyert and March, Simon, Arrow, and Cross.

The "classic defense" against the empirical discrepancy turns on the "willingness to concede that the rationality assumptions of economic theory are not descriptive of the process by which decisions are reached and, further, that most decisions actually emerge from response repertoires developed over a period of time by what may broadly be termed 'adaptive' or learning processes" (Winter 1986, p. 244). Given sufficient learning time and a competitive environment, adaptive actors will eventually arrive at prices and production levels similar to those they might have calculated if they had the information and inclination to do so.

This "as if" principle (Winter 1986, p. 244) works reasonably well in competitive markets for private goods where prices and resource allocations are relatively well-behaved. The economist can then calculate equilibria on the assumption of maximizing-behavior without concern that the calculations do not describe the actual process by which adaptive actors converge with the analytic shortcut. Consequently, the poor fit between the behavioral assumptions and the findings from experimental economics and psychology has not prevented the rational choice model from generating reasonably accurate predictions about aggregate market tendencies and reasonably effective policies for altering them (Lynn 1986, p. 199).

Nevertheless, even in the realm of pure private goods, the "as if" principle works only so long as the rate of environmental change is less than the rate of adaptation (Cross 1983). Otherwise, adaptive behaviors will fail to converge at prices that clear the market. Thus "moderates" like Lucas and Zeckhauser concede that the "psychological approach" is sometimes necessary, in which the adaptive behavior must be studied directly. Fortunately (not just for economists but for all of us fed by the "invisible hand"), economic life has sufficient regularity that adaptive processes usually arrive willy-nilly at the necessary "steady states," generating "decision rules that are found to work over a range of situations and hence are no longer revised appreciably as more experience accumulates" (Lucas 1986, p. 218).

The problem in the "social and political sphere" is that public goods are not so well-behaved, due to neighborhood effects, uncertainty about free-riders, and the absence of competitive pressures in most nonmarket transactions. Even in a relatively stable environment, nonexcludable goods are prone to trap adaptive actors in local maxima that do not compromise survival and need not correspond to the global solution. Hence the need to forgo the analytic convenience of rational choice assumptions and model the adaptive process directly, as in these simulations.

The broad conclusion is that the "as if" principle can be very useful for most of the private goods studied by economists and few of the public goods that intrigue sociologists. Paradoxically, economists need not worry if market actors actually set prices and production based on rules of thumb (including "fairness"), so long as the norms are acquired and abandoned in response to market signals and without excessive delay. Sociologists, on the other hand, do not enjoy the same latitude. Because the "as if" principle is generally unavailable for public goods, sociologists working with rational choice models are forced to assume that actors in the social and political sphere really are tough-minded utility maximizers, which economists focusing on market behavior do not need to do!

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