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FORMAL MODELS OF COLLECTIVE ACTION

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Abstract

This review focuses on formal theories and models of collective action. There are many types of collective action, and they cannot all be captured with the same formal model. Four types of models are reviewed: single-actor models which treat the "group" behavior as given; models of the interdependent aggregation of individual choices into collective action; models of the collective decisions of individuals with different interests; and models of the dynamic interactions among collective actors and their opponents. All models require simplifying assumptions about some aspects of a situation so that others may be addressed. Models of the aggregation of individual choices have shown the greatest recent growth, have employed a wide variety of assumptions about individual behavior and coordination mechanisms, have identified complex interaction effects of group heterogeneity, and generally exhibit thresholds, discontinuities, and internal group differentiation. Models of dynamic interactions require further development but promise to be enriched by accumulating empirical time series data on collective events. Greater attention is urged to technical issues of formal symbolic mathematical analysis, experimental design, response surface analysis, and technical problems in the reduction and presentation of complex interactions.

INTRODUCTION

Formal collective action theory has undergone an enormous growth and elaboration within the past few years, with a major shift from focusing on individual decisions to focusing on group structure and interaction. This theory

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draws on and speaks to the larger empirical literature on collective action and social movements, but mostly in indirect ways. Only for the very simplest individual decision models have there been empirical studies that could be said to test predictions. This article centers on the newest formal theory, with brief reviews of older formal theories and empirical data on individual decisions.[1]

This review begins with a brief summary of the historical grounding of collective action theory in Mancur Olson's work, and of the way the problem has been reformulated by subsequent theorists. It provides abbreviated reviews of public goods economics and of models of individual decisions which treat the "group" as given, including a sketch of some of the empirical findings that reflect on such models. The core of this review discusses models that treat collectivities rather than individuals as the units of analysis. A brief conclusion points to the complex and contingent nature of the newest findings and shows how some patterns are emerging amidst the complexity.

The process of preparing this article involved a close review of the mathematics, but it is impossible within its space limitations to present equations and derivations. Results are also usually too complex to be adequately summarized. Instead, words are used to say very generally what the models do, with some emphasis on strategies of analysis and presentation. I was able to check some of the simpler models in a spreadsheet; in all cases I could duplicate the reported results, and several times found additional patterns in the data, which I report. The process of the review also led me to reflect upon principles and standards of formalizations and simulations, which I discuss briefly at the end of the article.

Mancur Olson and The Logic of Collective Action

To the uninitiated, the term "collective action" would seem to have at its definitional core the idea that people do something together, and recent scholarship is beginning to return to this idea. But since the late 1960s, most literate social scientists have seen the core definitional content of the term "collective action" as a common or shared interest among a group of people. This view is derived from Mancur Olson's *The Logic of Collective Action* (1965), especially his assertion that "rational, self-interested individuals will not act to achieve their common or group interests" (1965:2) and a chapter which offers a mathematical "proof" of this assertion coupled with a persuasive verbal description of the "free rider problem."

OLSON'S CONTRIBUTION Prior to Olson, social scientists generally assumed that there was a natural tendency for people with shared interests to act together

[1]For a recent review of empirical research on "collective events," (which are a subset of the phenomena understood as "collective action") see Olzak 1989.

in pursuit of those interests, that is, that there was an unproblematic congruence between individual interests and group interests. Olson argued otherwise. Economists had long argued that rational individuals would not voluntarily contribute money to pay for public goods such as armies, legislatures, parks, public schools, or sewage systems, thus explaining why coercive taxation is necessary. Olson argued that all group goals or group interests were subject to the same dilemma. He defined a collective good as one which, if provided to one member of a group, cannot be withheld from any other member (called nonexcludability or "impossibility of exclusion;" Hardin 1982, p. 16).[2] Collective action was thus defined as any action which provides a collective good. Although this formal definition does not exclude individual actions, and the individual provision of collective goods is an important phenomenon, most scholars focus on actions that are behaviorally collective as well.

Olson argued that if the benefits of a collective good cannot be withheld from nonparticipants, rational individuals are motivated to free ride on the contributions of others. Furthermore, he argued, this temptation would be greater the bigger the group, where the benefits of a contribution would have to be divided up among more people, and any one person's contribution would be less likely to make a noticeable difference in the outcome. Thus, he said, collective action is "irrational." If he had been a sociologist, Olson might have used this argument to launch a theory of the nonrational or nonindividualist bases of collective action. But since he was an economist, he argued that collective action must be accompanied by private excludable selective incentives that reward participants or punish nonparticipants, and he devoted the rest of his book to defending the empirical claim that such selective incentives can be found in a variety of historical instances of collective action.

The importance of Olson's argument to the history of social science cannot be overestimated. Prior to Olson, social scientists typically assumed that people would instinctively or naturally act on common interests, and that inaction needed to be explained. Explanations typically took two forms. In one, the connection between interest and action was taken as so automatic that inaction itself was taken as proof that there must not actually be a collective interest. In the other, inaction was explained in terms of individual "apathy" (which was, of course, indicated by the failure to act) or by some sort of communal deficit (of organization, solidarity, education, or resources) which prevented people from acting on their interests.

After Olson, most social scientists treat collective action as problematic.

[2]In the early work of Samuelson (1954), Head 1974) and others, "pure" public goods are defined by *both* nonexcludability and "jointness of supply." In later work, jointness of supply tends to be treated as a variable, regardless of the formal definition used. For a good summary of this issue see Hardin 1982 (pp. 17–20).

That is, they assume that collective *inaction* is natural even in the face of common interests, and that it is collective action that needs to be explained. This is the central problem for the "resource mobilization" (e.g. McCarthy & Zald 1973, 1977) and "political opportunity" (e.g. McAdam 1982) theories of social movements. (See also Snyder & Tilly 1972, Gamson 1990, Tilly 1978, Oberschall 1973, and Jenkins 1983 for greater elaboration of these theories than is possible here.) Instead of viewing "grievances" as automatically generating action, these theories stress resources, organizational capacities, and shifts in the polity as central to determining which grievances get acted upon.

THE PROBLEM WITH OLSON'S PROBLEM The development of formal collective action theory begins with a critique of Olson. Plausible as it may seem, Olson's argument is wrong on its own terms. Selective incentives cannot logically solve the collective action dilemma. The problem is that somebody has to pay for the selective incentive, and paying for a selective incentive is, itself, a collective action in that it provides a benefit to everyone interested in the collective good, not just the people who pay for the incentive. Thus, the free rider problem adheres just as much to providing selective incentives to induce others to provide collective goods as to the original collective action problem (see Frohlich & Oppenheimer 1970, Frohlich et al 1975, Oliver 1980). If collective action were truly always irrational, then selective incentives could not solve the problem.

More generally, Olson's equations and his verbal arguments entail a number of implicit assumptions, and it is the truth or falsehood of those assumptions that makes collective action rational or irrational. Different critics have focused on different assumptions and have explained the problems and contradictions in different ways (see Frohlich & Oppenheimer 1970, Frohlich et al 1975, Oliver 1980, Chamberlin 1974, Schofield 1975, Bonacich et. al, 1976, Smith 1976, Hardin 1982, Oliver, Marwell & Teixeira 1985, Oliver & Marwell 1988, Kimura 1989). A fair summary would be to say that there are many situations that give rise to "Olson's problem," but the scope of this problem is narrower than most people would understand by the phrases "collective action" or "collective goods." All theorists would predict with Olson that unconnected self-interested individuals will not spontaneously make small contributions which make no detectable difference in the provision of an expensive collective good, even if the sum of their contributions would benefit everyone. What the critics say is that, contrary to Olson's arguments, interdependence and coordination can change individual decisions even without private incentives, and that many collective goods can, in fact, be provided by a small number of individuals making large contributions through an appropriate technology (e.g. lobbying Congress).

Olson's "group size" argument—that collective action is more unlikely in larger groups—has also been subject to extensive critique. (See Hardin 1982 for a review of these debates.) In the formal collective action literature it has been repeatedly argued that this claim is either tautological or wrong. Olson and his critics agree that the real issue is whether an individual can make a noticeable difference in the provision level of a collective good. Olson confuses the issue: first he virtually defines a large group as one in which contributions are not noticeable (1965, p. 44), but then in a footnote he rejects the tautology and offers the empirical claim that noticeability is very unlikely in a larger group (1965, p. 49). It is this empirical claim that has been challenged. Nonexcludable collective goods usually have high levels of jointness of supply, in which the cost of the good is invariant with the number who enjoy it. When jointness of supply is high, there is no simple relation between the size of the group and the noticeability of contributions or the prospects for collective action (Bonacich et al 1976, Mitchell 1979, 1980, Hardin 1982, Oliver & Marwell 1988).

Because this issue has become quite confused in the literature, it may be worthwhile to elaborate. Put simply, in some situations the group size effect will be negative, and in others positive. You have to know the details of a particular situation before you can know how group size will affect the prospects for collective action. If you are creating a model, you have to put a group size effect into the model to get one out. If the theorist assumes that costs increase or individual benefits decrease with group size, there will be a negative "group size" effect on action. If the theorist assumes that the good has high jointness of supply, so that costs and benefits do not vary with group size, there will either be no "group size" effect, or it will be positive.

Sometimes theorists build implicit group size effects into their models. A negative group size effect is forced whenever an individual's payoff is defined as something divided by group size, either as a proportion of a total share or as a function of the proportion of cooperators in a group. By contrast, defining the individual payoff as a function of the raw number of cooperators builds in a positive group size effect by implicitly assuming jointness of supply. In more complex models, positive or negative "group size effects" are often implicit in the details of a coordination or sanctioning system.

The Purpose and Project of Formal Collective Action Theory

The discussion of the "group size" effect implies a more general point. The most important result of twenty years of formal collective action theory is that collective action is not a unitary phenomenon. That is, the range of events reasonable social scientists subsume under the term "collective action" is much too complex and diverse to allow simple generalizations about its causes, effects, or dynamics. Titles like *The Logic of Collective Action* (Olson 1965) or *The Mathematics of Collective Action* (Coleman 1973) have been deeply misleading, even though their contents are illuminating. Questions like "Do people free ride?" and "Is collective action rational or irrational?" are too general to guide research. More useful questions are: When do people free ride? Under what conditions is collective action rational? How is collective action coordinated? What factors affect outcomes of strategic interactions among collective actors? What are the important types of collective action?

Collective action theorists increasingly view their task as using formal tools to illuminate processes and dynamics within particular classes of collective action. Implicitly, they are also helping to construct a typology of collective actions by identifying crucial factors that determine forms and trajectories of action.

As formal theorists have moved beyond Olson's problem into the theoretical space it opened, they have implicitly returned to the older conception of collective action as something people do together. That is, although the existence of a collective interest is taken as the context within which collective action is studied, theoretical attention is devoted less to the interest itself as causative, and more to the social and organizational processes that make action possible. Most formal theories of collective action have some sort of individual decision by rational cost/benefit calculus at their core, but the question of individual versus group interest is not the major focus of their attention. A few major theories have no "interest" concepts at all, and instead employ cognitive processing or adaptive learning models.

Models of collective action operate at different levels. The simplest and oldest focus on one individual at a time, and ask when that individual will act or contribute to some form of collective action. They collapse "the group" into a generalized other or a simple payoff equation. Many theoretical and empirical articles have addressed the conditions that affect individuals' choices in collective action. This review can only briefly indicate what is known about the individual predictors of participation.

More complex models are concerned with the joint action of many individuals within one collectivity. In these models, the problem is whether individuals will be willing and able to coordinate their actions into a single joint action. For most scholars working in the area, this is the problem evoked by the phrase "collective action." Scholars have explored variations in heterogeneous distributions of important traits across individuals, structures of network linkages among them, and coordination mechanisms. Although most of these models work in the cost/benefit paradigm, some instead are grounded in adaptive learning or cognitive processing psychologies. Most recent theoretical breakthroughs involve single collectivity models, and this review gives greatest attention to them, even though they are too new to have generated much empirical research.

Another set of models focusing on a single collectivity may be called "collective decision" models. In these, the collectivity contains individuals with many interests who can engage in many collective actions, and the question is, which subset of actions will be jointly chosen by the members.

This problem of "legislative bargaining" in political science is beyond the scope of this review. However, the few sociological models within this tradition are reviewed; again there is little relevant empirical research.

Finally, some models address not the actions of one collectivity at a time, but the strategic interactions between collectivities, particularly between movements and their opponents, usually conceived as states or regimes. These models ignore most within-collectivity complexities to permit consideration of interaction and strategy. These models have the greatest immediate potential of being linked to empirical research.

These four levels of analysis are all simplifications of a complex process which includes all of them at once. We might imagine a long-range goal of putting all levels together in one enormous theoretical model, something comparable to physical science simulations of global weather patterns or the global environment. However, enormous models like these are still not producing reliable results for physical scientists, who are building on a much larger base of well-understood simple principles. Scholars of collective action need theory development and empirical research before contemplating grander models. We accept trade-offs. We simplify some problems to address the complexities of others.

INDIVIDUAL DECISION MODELS

Models of a single actor collapse "the group" into an undifferentiated other in a payoff structure. Olson (1965) employs a single-actor model, and many such models are reformulations of Olson's. Hardin (1982) provides a comprehensive review of these models through the late 1970s, discussing a wide variety of dimensions of collective action with special emphases on the "asymmetries" of action and the formation of implicit contractual solutions through conventions and norms.

Since Hardin (1971) analyzed Olson's problem as a prisoner's dilemma, many scholars have used game theoretic payoff matrices to debate the likely outcomes of collective action, including those who argue it is not a prisoner's dilemma but a coordination or assurance game (e.g. Runge 1984). All payoff-matrix accounts of collective action treat the "group" as a unitary actor and summarize the problem as eight payoffs in a matrix. In practice, payoff matrices are used to illustrate verbal arguments, rather than as analytic tools.[3]

[3]Shofield (1975) uses characteristic functions to address Hardin's problem and shows that collective action should become unanimous if a coalition favoring action forms. For recent debates on the utility of game theory for understanding collective action, see the special issue of *Rationality and Society*, Vol. 4, No. 1, 1992. This article also does not discuss the coalition-bargaining game tradition with its use of characteristic functions. For overviews of recent theory and research on game theory, see Kahan & Rapoport (1984), Komorita (1983), Michener & Potter (1981), Myerson (1991), Owen (1982), and Shubik (1982).

A great variety of individual decision models have organized much theory and research on collective action. In general, these provide an equation for the net payoff of participating in collective action as a function of the benefit of the collective good, the benefit of "selective incentives" and the costs of participation. They differ greatly in the details of the specifications of these benefits and costs. Authors rarely manipulate these equations mathematically to produce derivations or new results, but instead use them heuristically to organize a term by term verbal discussion of the determinants of participation.

Although most economists and also critics of rational choice models (e.g. Gamson 1990) assume that individual decision models require "objective" costs and benefits, social scientists who use the paradigm are actually grounded in the psychological model of subjective expected utility, where all terms are assumed to be those subjectively perceived by actors. Klandermans (1984) calls for explicit use of the subjective expected utility model, with explicit recognition that these subjective terms change over time and can be influenced by intentional communications. Opp (1986, 1989) argues that subjective models are not tautological, because reliable survey techniques exist for measuring attitudes. Debates about whether subjective utility models are the best representations of the ways individuals think are beyond the scope of this review (e.g. Roemer 1978, 1979, Ferree 1992, Gamson 1992).

Empirical Data and Individual Decision Models

Individual decision models of collective action have had a great impact on empirical research. The level of interest in the collective good is most commonly operationalized with attitude scales measuring the intensity of opinion about a collective issue such as Cruise missiles (Klandermans & Oegema 1987), an upcoming union contract (Klandermans 1984), neighborhood problems (Oliver 1984), radiation exposure from Three Mile Island (Walsh & Warland 1983), or nuclear weapons (Opp 1988). Such scales typically have the predicted strong positive relation to measures of participation, although they do not always distinguish token members from active participants (Oliver 1984).

These theories generally have some term for efficacy, the perception that one's actions make a difference in accomplishing goals, which is the hope and urgency that marks historic moments of peak collective action (e.g. McAdam 1982). Research generally finds that participants in movement activities are more optimistic than nonparticipants about the prospect of change and about the efficacy of their participation, including African Americans between 1930 and 1970 (McAdam 1982), riot participants of the 1960s (Forward & Williams 1970, Paige 1971, Seeman 1975) and European social movement protests in the 1980s (Finkel et al 1989, Klandermans 1984, Opp 1988).

In theoretical models, the potential for free riding is most commonly captured by multiplying the individual's interest in the collective good by a term capturing the probability that the individual's contribution will make a difference in the collective good. Empirically, the multiplicative model rarely yields a significant improvement over a linear model including the interest and efficacy terms.[4] Empirical research also suggests that while perceived collective efficacy is often important, the individual free riding dilemma is not. Walsh & Warland (1983) identified people who had an opinion about restarting the Three Mile Island reactor but were not participating in a group contesting the issue. They found few self-conscious free riders who were letting others do the work; most gave as reasons for nonparticipation their criticisms of the organizations, not having been asked to join, or lack of time. In a series of natural experiments, Marwell & Ames (1979, 1980, 1981, also Alfano & Marwell 1980) generally found that average "free riding" levels of about 50%; free riding was higher when subjects thought they were in larger groups. Self-reported individual efficacy levels are often highly implausible. Opp (1989) finds that movement participants attribute to themselves efficacy they believe the whole movement has.

Olson's concept of "selective incentives" has received important elaboration, with attention to the individual incentives that help to reward participation or punish nonparticipation. Oliver (1980) demonstrated formal differences between rewards and punishments as incentives. Most scholars today follow Clark & Wilson (1961) and James Q. Wilson (1973) in recognizing three broad types of incentives: material, solidary, and purposive. Material incentives are discussed by Olson and include salaries, insurance programs, and threats of physical or economic retaliation. Solidary incentives arise from social relations with other participants, such as praise, respect, and friendship or shame, contempt, and ostracism. Purposive incentives arise from internalized norms and values in which a person's self-esteem depends on doing the right thing. These concepts of solidary and purposive incentives have permitted theorists to incorporate the influences of social networks and culture and socialization. Direct measures of solidary and purposive incentives have the expected positive relations (Opp 1988, Klandermans 1984, Klandermans & Oegema 1987, Knoke 1988). Research indicating the strong effects of networks and socialization on collective action also can be construed as evidence for solidary and purposive incentives (see Snow & Oliver 1993).

"Cost" terms in individual decision models are more problematic. Higher

[4] I base this claim on my own analyses and personal communications with other analysts. These nonsignificant results are rarely published, and most publications use linear models. One exception is Opp, who often publishes the multiplicative models on theoretical grounds and a comparison of R^2s.

costs should reduce action, but the data do not consistently show this pattern. Macro-level analyses of repression, resources, and political opportunities support a cost-benefit account, i.e. that there is more collective action when costs are lower and potential benefits are higher (McAdam 1982, Tilly et al 1975, Tilly 1978, Oberschall 1973). But measures of subjective costs do not have the expected negative relation to action. Hirsch (1990) found that participants in a campus divestment protest believed they were bearing heavy costs and making sacrifices, while nonparticipants downplayed costs and assumed that participants were gaining intrinsic benefits. Opp (1988, 1989) found a similar pattern regarding assessment of costs and risks associated with antinuclear protest activity. Relatedly, people with more money or free time should have lower opportunity costs, but wealthy people give a lower proportion of their income to charity than poorer people (Sugden, 1984, Bergstrom, Blume & Varian 1986, Andreoni 1988, 1989, 1990), and people who are already busy are more likely to participate in a new activity (Oliver 1984).

We may summarize the empirical data about individual decisions by saying that cost/benefits models have predictive value when the right costs and benefits are included, but different costs and benefits seem salient in different circumstances, and no one has offered a coherent theory to predict these variations.

PUBLIC GOODS ECONOMICS

Economists and some political scientists investigate problems similar to collective action with the standard methods of economics, including plotting indifference curves and identifying equilibria, patterns of collective action which are stable in the sense that no individual would be motivated to depart from it in isolation. There is an enormous literature in the economics of public goods provision that cannot be reviewed here, but see Buchanan (1968) and Tullock (1974), Boadway & Wildasin (1984), Boadway & Bruce (1984), Johansson (1991) and Cornes & Sandler (1986). Sociologists should note that there are many "types" of public goods investigated with different models.

Economists have explored the equilibrium solutions for different production functions with varying assumptions about interdependence and coordination (e.g. Cornes & Sandler 1983, 1984a,b, 1985a,b, 1986, Bergstrom & Cornes 1983, Cremer & Riordan 1985, Buchanan & Pinto Barbosa 1980) including weakest-link and best-shot rules (Hirschleifer 1983), provision of public goods by single individuals such as dragon-slayers (Bliss & Nalebuff 1984), contracts (Bagnoli & McKee 1991), matching rules (Guttman 1978), negotiation processes (Mas-Colell 1980), and profit-seeking political entrepreneurs (Frohlich, Oppenheimer, and Young 1971, Frohlich & Oppenheimer 1974, Bagnoli & Lipman 1989); Laver (1980) critiques "political" solutions. There are models of optimal central taxation or allocation schemes for public goods (e.g. Groves & Ledyard 1977, 1980, Lau, Sheshinski & Stiglitz 1978). In the theory of clubs, individuals join together to provide a nondivisible but excludable good (Hillman 1977, Buchanan 1965, Ng 1973, Helpman & Hillman 1977, Zech 1982); Smith (1985) applies club theory to environmental lobbies.

Economists also model pure altruism. They vary in whether people value only others' happiness (Sugden, 1984, Bergstrom, Blume & Varian 1986), or whether they are also motivated by the "warm glow" of knowing they did the right thing (Andreoni 1988, 1989, 1990). These issues are explored with data on rates of giving by income, and the extent to which individual giving is crowded out by public welfare. This debate parallels collective action theory's distinction between valuing a collective good and the purposive incentive of doing the right thing about pursuing the good.

COLLECTIVE DECISIONS

For the problem of resolving competing interests within a group, Coleman (1973) develops a matrix model for what may be called collective decision making. He defines vectors of actors and outcomes, and matrices for each actor's control over and interest in each outcome, where actors lack full control over outcomes that interest them. Matrix multiplications represent bargaining or exchange processes that determine whose interests are achieved, the general principle being that control over events in which others are interested yields the greatest power. Standardization rules are applied to express interest and control as proportions of appropriate totals. Each outcome is assumed to have a probability of occurrence proportional to the total amount of power directed toward that event. Coleman (1988, 1989) extends this mode of analysis to other problems, particularly to the "second order problems" of sanctioning and norm creation systems, showing (in line with Heckathorn's results, below) that such systems can produce zeal, the overprovision of collective goods.

Based on his prior work on community influence systems (Marsden & Laumann 1977, Laumann, Marsden, and Galaskiewicz 1977), Marsden (1981) adds influence processes and networks to the basic model by creating a standardized actor-by-actor matrix to capture the extent to which each actor modifies his expressed interests in light of the interests of another. He shows that contradictory interests lead control or resources to be held out of the system. He also investigates simple patterns of interaction among influence, control, and interest distributions, showing how these affect the total level of resource mobilization in the system and the status and power of actors.

MODELS OF REGIME-MOVEMENT INTERACTION

Several new models address the problem of interactions between collectivities, especially between movements and regimes. An important line of recent empirical work stresses interaction of movements and states in shaping cycles of protest. Simple early works include McAdam's (1983) demonstration that peaks of protest activity cluster around tactical innovations, and Pitcher et al's (1978) formal model of collective violence. Both argue that an innovative protest first catches the regime off guard, and thus diffuses because of its success, and then is brought under control by more effective social control or repression. McAdam's (1982) political process model has never been formalized but is expressed as a diagram of causal flows and feedback loops which could be modeled. McAdam presents data to support his model. Recent work (e.g. Koopmans 1992) focuses on empirical evidence that recent European protest cycles begin with confrontative nonviolent tactics which increase in both moderation and institutionalization on the one hand and radicalism and violence on the other, a pattern best explained by shifts in the state's response to confrontative nonviolent actions.

There are several recent formalized attempts to capture the complexities of dynamic interplay between movements and regimes. All are promising but flawed by problems of metric or specification. However, because there are also significant bodies of empirical data about collective events over time, this type of model might generate testable empirical propositions that could take metricized inputs from empirical cases.

Chong (1991) develops a supply and demand model based on McPhee's (1966) model of consumer demand. Popular mobilization both expresses the demand for public goods and creates new demand; mobilization may stimulate opponent mobilization. The government responds to mobilization by supplying policies which may favor either proponents or opponents. Chong's regime is never repressive, only responsive to opponents. All three actors (proponents, opponents, government) have baseline tendencies to act which are modified by the actions of others. Factors captured by the model include bandwagon rates (mobilization due to prior successes), contagion rates, reactive mobilizations, and differential regime sensitivity to proponent and opponent mobilization. There are extensive substantive discussions of the rationale for each relationship in each equation. However, many of these discussions explicitly argue for nonlinearities and interaction effects, while Chong's equations are all linear. Also, the specification of the model implies that groups are homogeneous. Chong does not address the question of how these simplifications affect his results.

Chong's effort is also marred by inattention to metric or normalization. Mobilization is in units of people and cannot have the same metric as government policies. In the model, policy variables are always multiplied by coefficients which can bring them into the scale of mobilization, and Chong always works with these products in his examples, thus sidestepping the metric issue. It would be preferable, however, to address it directly so that his models could be more directly interpreted.

Despite these problems, Chong's work is important. His mathematical sophistication is greater than most. He sets up his models symbolically and uses the mathematics of difference equations to solve for equilibrium conditions and time paths. Thus the parameters themselves are interpreted as variables which jointly define qualitatively different structural conditions which produce different patterns of results. Some structural conditions produce stable equilibria, others produce oscillations, and others produce spirals to infinity. These are potentially powerful results which should be pursued with nonlinear specifications of relations and specific treatment of the issue of metric.

Opp (1991) models the interaction between state actors and collective actors, and explores the effects of a sudden grievance and the distributions of the original propensity to act among the actors. Opp's model is designed to capture the pattern of his empirical findings about the effects of repression in the German peace movement (Opp & Roehl 1990), in which the net effects are positive, due to the indirect "radicalizing" effects on incentives, despite the negative direct effects of cost on action. Unfortunately, it is impossible to determine the long-term utility of the model because its present form is fatally flawed. For no apparent reason, the range of costs is 15 times that of benefits, thus making most net payoffs negative, a problem Opp deals with by fiat, declaring in defiance of theory that some negative net payoffs will lead to action. Slope coefficients for equations are similarly chosen arbitrarily. Opp's only comment on the choice of parameterization is that the model behaves differently depending on variable ranges and parameters, and that he picked those that seemed to him to give "plausible results" in terms of the time path of the model, i.e. those which fit his single empirical case. Though flawed in execution, this general model may be worth pursing more rigorously.

Hoover & Kowalewski (1992, also Kowalewski & Hoover 1992a,b) focus on modeling the link between dissent and repression, arguing persuasively from a review of 101 empirical studies that states cannot be conceived as static "targets" and that feedback loops known to exist in the relations make cross-sectional analysis misleading. In their models, movements and states have stocks of resources and grievances which are increased or decreased depending on their own actions, those of their opponent, and those of third parties. They distinguish between the scope and intensity of action, which seems similar to empirical findings about the difference between widespread moderate action and violence committed by a radical cadre (e.g. Koopmans 1992).

They explore several key variations. The first is the nature of the feedback between movement actions and state actions, whether it is positive, negative, or zero and whether actors respond to intensity, scope, or an average of the two. They report that all their models converge rapidly to stable equilibria, and that positive feedbacks (mutual sensitivity) produce the highest levels of ongoing conflict (Hoover & Kowalewski 1992), and that being imperturbable to the opponent reduces it. They model the response of these equilibrium conflicts to external "shocks," including war (Hoover & Kowalewski 1992), various conflict resolution interventions (Kowalewski & Hoover 1992a), and shifts in political opportunities (Kowalewski & Hoover 1992b). They also argue that both the state and the movement can be internally divided. They construct a typology of distinct orientations actors might have, show how different orientations lead to different strategic choices in different contexts, and identify the likely overall patterns according to how many of the orientation types prefer each strategy (Kowalewski & Hoover 1992b).

Hoover & Kowalewski control metrics by setting all variables (grievances, resources, and actions) to the same range, 0 to 100, and interpreting their values as percentages of the maxima. However, all parameters in the model are specific numerical linear coefficients, most of which seem quite arbitrary and a few of which seem wrong. No attempt is made to assess the sensitivity of the model to changes of parameters, and all reported results are constrained by these choices.

SINGLE COLLECTIVITY MODELS

The greatest theoretical elaboration has occurred among models of the ways individual actions interdependently aggregate into a collective action. All these models assume a unitary collective action and single dimensions of interest (or reinforcement) and resources. They vary in assumptions made about individual choices, and in the structures of interdependence among actors.

Critical Mass Theory

Oberschall (1980, 1989) provides simple models for the effects of group heterogeneity on protest waves, but most of the recent emphasis on heterogeneous groups arises from critical mass theory which emphasizes the role of actors who behave differently from typical group members (Oliver et al 1985, Oliver & Marwell 1988, Marwell et al 1988, Prahl et al 1991, Marwell & Oliver 1993). Oliver et al (1985) show how the shape of the production function defines different "types" of collective action with different dynamics. They argue that strategic gaming is the potential problem for decelerating production functions, while efficacy is the central problem for accelerating functions. They assume a common metric for costs and benefits, and they develop formal representations of concepts of surplus, order effects, indirect production, and contracts. Most results are analytic; numerical examples are taken as fixed, and the sensitivity of results is not assessed.

Oliver & Marwell (1988) use verbal argument and one numerical example to show that Olson's "group size" claims are not general but contingent, and that most collective goods have high jointness of supply which produces a positive group size effect, although they refer to more complex analyses they do not report.

Marwell et al (1988) investigate the interactions among group heterogeneity (both in interests and resources) and organizing cost, network density and network centralization, using an accelerating production function and an organizer-centered mobilization of an all or none contract. Findings are: (i) increasing heterogeneity around a given resource or interest mean improves success rates when the mean would produce failure and increases failure when the mean would produce success; (ii) organizing costs and network density have the predicted negative and positive effects, respectively, on collective action; (iii) when groups are heterogeneous, network centralization increases the rate of collective action by increasing the probability that an organizer will be tied to a few large contributors.

The core of the analysis is an experimental design and a Monte Carlo simulation. There are 6 possible values each for the two heterogeneity terms, 10 for costs and density, and 19 for centralization which taken together define a $6 \times 6 \times 10 \times 10 \times 19$ design with 68,400 cells. Since it was impossible to generate all possible combinations of parameters (2,794 cases were generated across several months' time), parameters were themselves randomly chosen from uniform distributions across their ranges, thus yielding a representative random sample of the full design. A further random component is the generation of heterogeneous groups with the indicated heterogeneity and network parameters. Output from the simulation is analyzed with standard regression techniques.

Oliver & Marwell (1991, also Marwell & Oliver 1993, Ch. 6) investigate the effects of information on the total contribution an organizer is able to mobilize. The problem is explored with two different models, each hinging on the fact that the mean of some top fraction of a distribution must be higher than the overall mean of the distribution. In both models, the cost of information is a reduction in the total number mobilized. Organizers must choose between having less information and mobilizing more people unselectively, or having more information and mobilizing fewer people more selectively. Formal derivations are coupled with a variety of numerical examples. Noting that relative costs can dwarf other findings, the authors report the general patterns that information is worth more as group heterogeneity increases, and that there is an optimum information level which increases as group heterogeneity increases.

Prahl et al (1991) explore the trade-offs between reach and selectivity in recruitment campaigns. Using an organizer-centered model and an accelerating production function, they develop an equilibrium equation for the expected total contribution from a heterogeneous group with a given mean, and show how this expected contribution varies as the parameters vary. All results exhibit multidimensional thresholds that must be exceeded before collective action can occur. There is a critical point above each threshold where contributions rise either steeply or discontinuously with small increases in any factor producing large effects. All factors approach asymptotes above the threshold, and analytic expressions are derived for the asymptotes. Resources and interest have continually positive effects, while increases in the interest level after the threshold add nothing to the outcome.

Sanctioning Systems

The general issue of "second order" collective action and sanctioning systems has been extensively analyzed by Heckathorn (1988, 1989, 1990, 1991) in a complex formal model which takes off from Oliver (1980) and Coleman (1988). Heckathorn is particularly concerned with situations in which an external control agent imposes collective sanctions on a group, so that if any group member defects, all are punished. Absent the sanction, all group members prefer to defect rather than cooperate, and they do not harm each other by doing so. The question is whether the external sanction leads group members to impose internal sanctions on each other to force cooperation. The short answer is that sanctions can cut either way: group members may either enforce compliance or use their sanctions to enforce rebellion and resistance to the external control agent.

Heckathorn's initial work (1988) uses static equations for one actor's decision at a time, to determine an equilibrium outcome under a given set of conditions, while later versions (1990) have set up complex algorithms of sequential decisions and iterations to equilibrium. The earlier work inputs a propensity to defect and calculates the value of using sanctions to prevent defection. The later work begins with universal defection and models actors actively choosing whether to use their sanctioning to enforce compliance or rebellion.

Heckathorn's conclusions are complex and contingent. Interactions among sanction strength, group cohesion, and the mix of individual and collective sanctions determine whether a group is indifferent to the external agent, compliant, or rebellious. He finds divisions of labor within groups. Group cooperation often arises through "hypocritical compliance," using sanctions to make others comply while defecting oneself, until there are enough sanctions to make everyone cooperate. Many groups retain this division of labor in equilibrium: some members cooperate with the external agent, while others bear the cost of the sanctions to enforce their cooperation.

Heckathorn's (1990) model is a complex iterated sequence of decision algorithms, and he gives few analytic results for group outcomes. Numerical examples of different regions of the response surface are coupled with verbal descriptions of the complex interactions and dynamics and some reports of the model's sensitivity to initial conditions. He assumes a common metric of costs and benefits, and he devotes some attention to determining how the ratios of the various costs and benefits affect the results, although not to the ways sanctioning costs might depend on others' behavior.

Heckathorn's (1988) analysis of sanctioning systems is organized around identifying the factors custodial agents might control. He reports that the stability of the compliance system is positively related to the strength of the external sanction, negatively related to the cost of control, and positively related to the degree of control among group members. Heckathorn also argues in this article that very small groups provide the best sanctioning systems. My own reanalysis of his equations replicates his reported results but also shows that the optimum group size goes up as the risk of a detected sanction goes down, especially when it is below 0.1. In this case, the conclusions about "group size" would differ if a broader range of conditions had been explored.

Addressing similar issues with payoff matrices, Heckathorn (1991) discusses the "altruist's dilemma" game in which egoists produce collectively rational outcomes, but altruists who try to maximize the other's payoff jointly produce collectively irrational outcomes. Heckathorn's best example is the "tragedy of the lawns," in which altruism or sanctions leads to a collectively irrational escalation in gardening standards.

Stochastic Learning Models

Macy (1989, 1990, 1991a,b) has explored the effects on collective action models of replacing the forward-looking rational actor with the backward-looking stochastic learner. Sometimes he argues that adaptive learning is a superior model and other times that it is an alternate model which can sometimes be more appropriate. Rational decisions are determinate one-shot choices that require intelligent processing of often-complex information about costs and benefits. Stochastic learning requires many repeated choice opportunities but less intelligence, and additionally assumes that behavioral choices are not determinate, but probabilistic functions of the rewards and punishments of past actions. Macy's learning model is rooted in a conventional Bush-Mosteller stochastic learning model for binary choice (Bush & Mosteller

1955), and the work of game theorists and psychologists in applying this model to rats playing the prisoner's dilemma (Rapoport & Chammah 1965, Flood et al 1983, Gardner et al 1984). Miller & Andreoni (1991) also use an adaptive learning model to create an evolutionary game theory analysis of free riding experiments, which they argue better explains the observed experimental results. Macy consistently identifies analytic solutions and reports on the stability of his results under varying parameterizations.

Macy (1990) applies his model to Oliver & Marwell's treatment of the critical mass, using an S-shaped logistic production function and varying the jointness of supply. Unlike most collective action models where nonaction has a payoff of zero, Macy makes the baseline provision level itself a variable, so that escaping collective misery can be compared with collectively improving on an already good situation. In this model, the aversive consequences of the privativistic baseline leads actors to experiment with prosocial behavior. With low jointness of supply, these experiments are not rewarded and thus not repeated, but when jointness of supply is high, the stochastic process virtually assures a moment when enough people try cooperation to cross the threshold of the critical mass. At the threshold, actors are stochastically alternating between prosocial action and privatism, i.e. sharing costs. However, as action continues, the group divides into a permanent class of prosocial good providers and a permanent class of free riders. Everyone is better off than they were in the aversive beginning, so the division of labor is an absorbing state. The free riders are better off than the providers, but the providers are enough better off than they were that they do not want to change.

Similar patterns arise when Macy (1989, 1991b) applies learning theory to the classic prisoner's dilemma. Although rational actors achieve mutual cooperation more easily, adaptive learners can achieve mutual cooperation if the negative consequences of mutual defection lead them to try cooperation at the same time. For adaptive learners, the key is some mechanism that leads them to synchronize their actions.

Macy (1991a) builds on Granovetter's (1978) threshold model, again translating it into a learning model with probabilistic thresholds (instead of probabilistic behavior). Additionally, he explores the difference between parallel independent decisions and sequential decision, and he shows how the results vary across a wide range of specifications, comparing them with similar rationalist results reported by others. The experimentation that characterizes a learning model provides the stochastic possibility of creating a critical mass of individuals with zero thresholds. The model predicts initial inaction due to low rewards for action, but the accumulation of aversive consequences of inaction leads the group to jointly evolve to a critical state where a minor event, i.e. a single random contributor, can start.

Simple Threshold Models

A number of models of group action are based on a simplified problem in which each person's propensity to act is a direct function of the number of others who are already acting. The first, and most influential, was Granovetter (1978). Using a constant group size, so that percentages and numbers are equivalent, he assumes that each person has a threshold percentage of others who must participate before she participates: those eager to participate have thresholds of 0%, while those who will never participate have thresholds of 100%.

Granovetter's most surprising claim is that minor perturbations in the standard deviation of a distribution produce massive discontinuous changes in the number of people acting, from about 6% to nearly 100% of the group. He claims that this result can be explained mathematically but not substantively, because it implies that this kind of collective action is virtually unpredictable, since tiny shifts in the heterogeneity of a group must happen all the time. However, my spreadsheet analysis of Granovetter's example indicates that substantive interpretation is straightforward and plausible: it is an example of a critical mass model.

The mathematical cause of his apparently shocking result is that Granovetter uses truncated normal distributions. Although negative numbers are meaningless as thresholds, normal distributions take on negative values as the standard deviation increases, a problem Granovetter deals with simply by recoding them to zero. Thus, as heterogeneity increases, the pool of zero-threshold self-activators grows. The big jump occurs when the standard deviation is just under half the mean, i.e. when the proportion of self-activators is approaching 5%. Below the jump, only the self-activators act. At the jump, they suddenly are a large enough group to exceed the threshold for people in the low end of the bell, and action "takes off." Thus the discontinuous effect is perfectly meaningful. If we keep our eye on the self-activators in a group, we ought to be able to observe the critical moment when the threshold occurs.[5]

Granovetter's analyses in the same article with uniform distributions, social structure, and spatial ordering point to the significance of zero thresholds and to the risks of "gaps" in a sparse distribution that might keep the dominos from falling. The domino image of cascading thresholds of action seems largely incorrect empirically, but one would generally expect clusters of people with similar thresholds and gaps between them.

[5]A less significant problem in the same figure is that the decline in the upper equilibrium happens much more slowly than the figure implies; the sketch has clearly been drawn freehand without reference to the scale on the horizontal axis. Anyone who attempted to interpret this part of the graph would have been seriously misled, but it appears no one tried.

A more recent model with a different orientation that also predicts behavior from the sheer number of participants is found in Naylor (1990). Built on Akerlof's (1980) social custom model and Schelling's (1978) discrete choice model, this model assumes that individuals gain some reputation-based benefit (i.e. a normative sanction) from participation which is proportional to the number of participants. (A collective good is assumed to exist but be irrelevant because individuals cannot make noticeable contributions.) Graphical solutions show the conditions for a stable equilibrium of participation. Naylor shows that if groups are homogeneous, the only stable equilibria are unanimous and zero participation, and that Schelling's (1978) dichotomous conclusions flow from the assumption of homogeneity. Consistent with Oliver & Marwell (1988), Naylor finds that heterogeneity reduces the size of the critical mass. Naylor & Cripps (1988) are cited as showing that the model is robust under changes in the distribution of normative incentives. If both joining and not joining evoke normative incentives (presumably from different sources), the rather obvious result is that any given individual will join only if more than half already have joined. Another modification has two levels of norms, one for those who believe in the custom, and another for those with a lower level of belief, which produces multiple equilibria.

Glance & Huberman (1993) use statistical theory to develop an elaborate mathematical representation of a n-person prisoner's dilemma in which payoffs depend only on the sheer number of contributors. Individual payoff is defined as total payoff divided by group size, forcing the negative group size effect claimed later as a result. Actions and information are probabilistic, and actors vary in the degree of time discounting of short-term defection payoffs versus long-term payoffs from building cooperation. These factors determine the fraction of other cooperators necessary to motivate cooperation, and the probability that this fraction is large enough. Dynamic analysis identifies the cutoffs defining four levels of increasing group size: (i) the one equilibrium for cooperation is optimum; (ii) cooperation is optimum but defection is a local equilibrium; (iii) defection is optimum but cooperation is a local equilibrium; (iv) the one equilibrium for defection is optimal.

In this model, groups beginning at a suboptimal equilibrium (either cooperation or defection) tend to remain at it until a probabilistic congruence of behavior pulls them out of the local equilibrium and they move suddenly toward the optimum, a result is similar to Macy's. Groups whose two equilibria are of equal optimality tend to flip-flop between them, their 50% average rates of cooperation disguising the fact that they are not dividing labor, but unanimously varying between the two. (This is different from Macy's finding of role differentiation.)

Cybernetic Control

McPhail (1991, 1993; also McPhail & Wohlstein 1986, McPhail & Tucker 1990, and McPhail et al 1992) has developed cybernetic control theory (Powers 1973) models of the ways collective action is coordinated by individuals adjusting their behavior to bring their perceptual signals in line with a reference signal. This work is grounded in his impressive compilation of empirical evidence to support the claim that there are no behavioral differences in how people do collective action that distinguish the traditional categories of "collective behavior," "collective action," or "social action" (McPhail 1991) as well as his (1989) reading of Mead that a common focus of attention cannot be treated as unimportant or unproblematic.

McPhail & Wohlstein (1986) differentiate forms of collective locomotion according to the ways in which they are coordinated, and they show experimentally that different instructions about how to coordinate action produce different degrees of coordination. For example, subjects did march to a common cadence when instructed to do so, but not when they were merely told to get from one point to another. More recent work uses simulations. McPhail et al (1992) develop a computer simulation for individual and collective action in temporary gatherings, describe how it works, and generate a wide variety of illustrative cases, each represented by a graphical "picture" of the group at various points in time. From 1 to 255 individuals can be in the gathering, each operating with one, two, or three control systems (seeking a destination, avoiding collisions, and seeking the path of other individuals). McPhail (1993) uses this simulation to show how clusters, arcs, and rings form in crowds as a consequence of common orientations.

Consensus Formation

Feinberg & Johnson (Johnson & Feinberg 1977, 1990, Feinberg & Johnson 1988, 1990a,b) develop models for the emergence of consensus in crowds. The core of their model is the well-established empirical phenomenon of "milling" in a crowd, wherein people move around and talk with others near them. Johnson & Feinberg use the computer to create large groups of people with various distributions of initial opinions and susceptibility, who are divided into spatial subgroups. People are influenced by the opinions of actors near them; some models also include a central agent who is trying to control or influence the crowd. An important additional element (also consistent with the empirical literature) is that those who disagree with the emerging consensus tend to back away from the scene, permitting consensus to form among those who remain. Crowd sequences either end with dispersal, if enough exit that too few remain to act, or end in some form of moderate or extreme action, if a high enough number of those remaining converge on the same choice.

In their various analyses, Johnson & Feinberg explore the effects of the size and density of crowds, the mix of initial opinions and suggestibility in the crowd, and variations in the strategy of an agent who is trying to mobilize an extreme response from the crowd. Because they create "groups" which stay in the computer's memory during execution, their models are large and time-consuming to execute. Most of their published results have been based on limited experimental designs. Johnson & Feinberg have only begun to explore the full implications of their models in terms of systematically varying factors that influence outcomes. Their work is entirely numerical to date and would be improved by formalization or sensitivity analysis. However, they have conducted experiments that vary the core parameters of the model.

Johnson & Feinberg's insight, that consensus is a product of both influence and exit, seems important for understanding the processes of action within a wide range of collectivities, especially organizations and also some informal networks or coalitions of organizations. Variations on their models are likely to prove useful for other substantive problems. For example, the construction and diffusion of a social movement ideology might work according to similar principles.

SUBSTANTIVE CONCLUSIONS

Recent models of collective action are diverse, representing attempts to capture different kinds of problems. One-actor models continue to be useful for simple empirical predictions of individual behavior, but they are providing few new theoretical breakthroughs. Models of collective decisions have great potential but do not seem to be the subject of much present work. Models of the strategic interaction between movements and their opponents are just beginning. These require much more development but will likely be enriched by empirical time series data. Recent empirical work suggests that it is especially important to model the ways states respond differently to different segments of the same movement, and to how these responses change over time.

Most recent development in collective action models has centered on the problem of the interdependence of individuals within collectivities. Even here, there is not yet enough information to permit confident conclusions. Emerging results reveal complex interactions that prevent simple generalizations. However, there are some patterns. First, models with quite different assumptions about individual decision processes and quite different assumptions about interdependence and coordination mechanisms all tend to yield predictions of thresholds and discontinuities, and predictions of internal divisions of labor within collectivities. Something like "critical mass" phenomena seem endemic to collective action. Second, the degree of group heterogeneity always changes results, but its effects vary: Sometimes it promotes action and sometimes it inhibits it. Clearly more research is required to understand the collective behavior of heterogeneous groups.

Finally, plausible formal representations of interdependence and mechanisms of coordination have permitted scholars to reengage some of the classic problems of the coordination of group action. Having transcended the limitations of the "free rider" question, scholars are able to acknowledge Olson's signal contribution in problematizing mobilization and collective action and then move on to other problems. The "rational actor" still has a place in these models but now shares the stage with the adaptive learner, the target of influence, the probabilistic decision-maker, and the inscrutable person who is willing to make a particular contribution for reasons known only to himself. All these individual actors are brought together in a variety of ways to coordinate their actions. Different theorists have been working with different coordination mechanisms, but we do not yet have the capacity to step away from these distinct analyses and identify types of or patterns among coordination mechanisms, nor have we identified the interactions among coordination mechanisms and other important features of collective action, particularly production functions. As work proceeds, we should hope to create theoretical typologies of collective action situations, so that we might identify the types of situations in which, for example, particular coordination mechanisms would be most effective. There is much to do.

APPENDIX: PRINCIPLES OF FORMAL ANALYSIS

This review has assumed the value of formal theory without trying to defend it to the skeptical, and space does not permit such a defense. However, the review has revealed a number of issues relevant to improving the quality of formal theorizing. Most important is to move away from illustrative examples and elaborate case studies to experimental designs and response surfaces. In the process, theorists need to attend to issues of mathematical consistency and metrics or normalizations.

The level of mathematical sophistication in the models reviewed is uneven. Some express equations symbolically and conduct standard mathematical exercises of solving for equilibria or creating reduced form equations. Others work only numerically, arbitrarily choosing numerical coefficients for equations and ranges for variables. Some models are developed within standard mathematical approaches such as linear equations, difference equations, or statistical theory, while others arise from ad hoc attempts to model problems not easily represented in standard ways. There is a general need to upgrade purely numerical models to a more general symbolic form, and to attempt to relate ad hoc models to mathematical approaches with known solutions or standard methods of approach.[6]

Metrics and functional specifications are also a problem. Many of the reviewed works devote no attention to determining plausible metrics for the relevant variables, nor to normalizing variables to some metric-free standard. Without either meaningful metrics or normalized variables, results can be profoundly distorted and misleading. In most models, it should be possible to express some parameters as functions of other parameters, so the metric of one can define the metric of others, thus reducing the dependence of results on metric. Numerical results are meaningless without specific attention to functional forms, parameterizations, and the metrics of variables.

The mathematical form of the functional relation between variables is often chosen arbitrarily and atheoretically, most often as some constant linear coefficient which has no theoretical justification, often even in the face of theoretical arguments that imply nonlinear relations. Even when theory guides parameterization, the review reveals insufficient attention to the sensitivity of models to choices in parameterizations. It is ultimately the parameters themselves that are of interest. We know that not all regimes have a responsiveness of 0.4 to mobilization (even if we knew the metrics of responsiveness and mobilization). What we want to know is how the degree or form of responsiveness of a regime to mobilization affects the trajectory of a system. Formal analysis of a model's equations can often reveal the critical interrelations among parameters that determine outcomes. If such results are unavailable, numerical analyses should be used to address the issue.

Uses of the Computer in Theorizing

There are conceptual differences among uses of the computer for formal models. The classic computer simulation is an elaborate case study in which all initial parameters and relationships are pre-determined, and the model is simply turned on to see how it changes over time. Such simulations are often useful in engineering and some biological or physical science applications, where there are clear bounds on the problem and a small number of well-measured fixed inputs and well-understood physical relationships that undergird the model, but they rarely have more than heuristic value in studies of collective action. In the physical sciences, numerical computations are also used to check the accuracy of analytic solutions to complex sets of equations. There are no cases of this in the social sciences, presumably because those analytic solutions we have are relatively simple.

[6]See Huckfeldt et al (1982) for pedagogic development of simple difference equation models of mobilization, diffusion, and dyadic interactions which show how to derive solutions for such models.

There are two important uses of computers by collective action theorists. The first is to investigate the behavior of a determinate mathematical model under varying initial conditions. In this case, the inputs of interest are varied systematically to determine the multidimensional response surface which shows how the dependent variable changes as a function of the independent variables. The second is Monte Carlo simulation of models with probabilistic or stochastic elements. In these cases, random number generators are used, each case contains a random error component, and the same inputs may yield different results depending on the random elements, so enough cases have to be generated to wash out random noise. In collective action models, the principal uses of Monte Carlo techniques are for investigating the effects of group heterogeneity and for stochastic models of individual choice. It is increasingly common to see these two models combined, using Monte Carlo techniques as part of a larger experimental design to construct a complex response surface.

From Case Studies to Experiments and Response Surfaces

Formal analysts of collective action need to escape the mentality of the case study simulation or numerical example and think instead in terms of experimental design and response surfaces. A response surface is a multidimensional graph that shows how a dependent variable changes as a function of many independent variables. The statistical concept of a response surface assumes a single quantitative dependent variable, but the response surface is an appropriate metaphor for qualitative outcomes as well. Investigations of complex models should be grounded in an experimental design with ranges and values of independent variables chosen to give adequate coverage of the response surface of interest. Ideally, every simulation's parameters, variable ranges, and functional forms should be varied and tested across all possible combinations. Obviously, this implies enormously large sample sizes and is impossible at the limit, but too many projects have involved no sensitivity analysis at all.

Experimental design is an appropriate way to conceptualize formal theorizing. Some things have to be held constant, and it is the theorist's job to identify these constant factors clearly as the assumptions and scope conditions of the theory. Within the theory, there are variables and functional relations among variables. If theory specifies the nature of the relation between variables, it can be treated as fixed, but if theory merely specifies some general dependence, the functional form itself may be considered a variable. Because it is impossible to vary everything at once in an experiment, some of those factors and parameters which the theory treats as variable will have to be held constant as others are varied. But if theorists view themselves as taking cross-sections from the larger conceptual response surface, they are likely to choose their variables and discuss them in more sensitive and contextualized way.

Attention to experimental design would also improve comparisons between different theoretical paradigms. Such comparisons are often impossible because models typically differ in a variety of ways, and it is difficult to isolate the effect of any one variable (e.g. rational choice versus adaptive learning assumptions). The case study mentality leads each author to choose a list of assumptions that seem most plausible. An experimental design mentality would lead authors to present more tightly controlled comparisons between models where as much as possible is held constant so that the effect of one factor can be identified.

Although older numerical analyses were constrained to limited designs by real dollar charges per CPU minute, today the greatest impediment to working with experimental designs instead of case studies is figuring out how to record and analyze the tens of thousands of data points it is now possible to produce. There is a tremendous need for technical advances in the design and analysis of efficient complex many-variable experiments, in the graphical display of complex interactions, and in data reduction techniques for conveying patterns of results first to the researcher, and then to readers. We also need statistical theory on the extent to which standard data-analytic techniques (e.g. regression, loglinear models, event history analysis) are appropriate tools for understanding the deductive relationships implied by simulations.

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