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Theories and Models of Diffusion in Sociology

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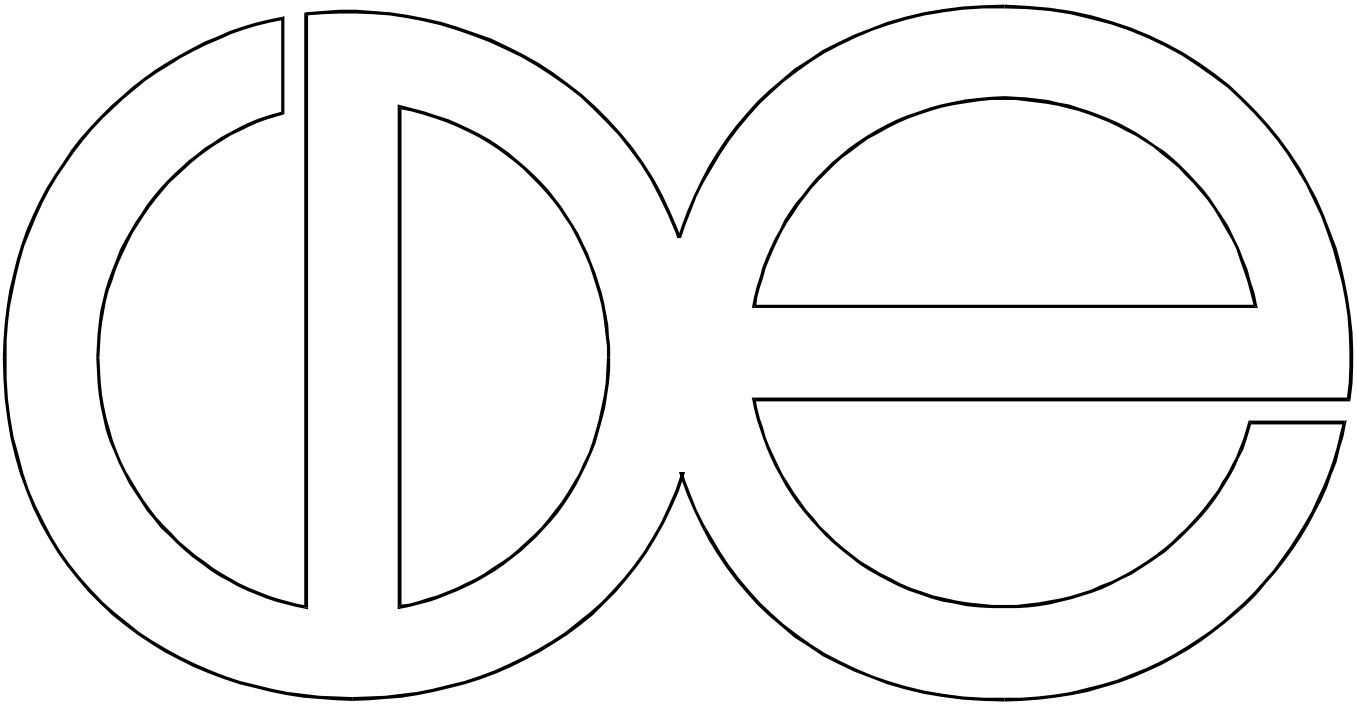

THEORIES AND MODELS OF DIFFUSION IN SOCIOLOGY

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I. OBJECTIVES

The original goal of this paper was to review the nature and applications of theories and models of diffusion in sociology. From the start it became evident, however, that the marginal advantages of producing a conventional review paper would not be substantial enough to contribute to the debate about the use of diffusion models in demographic analysis. Indeed, there are a number of very lucid, thorough, and authoritative reviews that are difficult to improve upon (see for example, Rogers, 1962, 1973, 1988, 1995 and Valente, 1995). But although the coverage and breadth of extant reviews is sufficient for a well-informed sociological audience, none of them is designed to inform demographic analysis except trivially, when a particular demographic process turns out to be a good illustration of a diffusion process. In addition, this literature is not geared to deal with generic problems faced in the explanation of demographic phenomena nor does it indicate how one can take advantage of new developments in the area. This gap is not altogether discouraging for it provides the material for a more productive discussion and elaboration of diffusion models and theories. And this is precisely what I set out to do in this paper. In particular, I have four interrelated goals or tasks:

(1) to identify the backbone of diffusion models and theories in sociology, and to show that **recent** formulations and applications require robust, well-specified theories about social systems, and about the positions that individuals engaged in or exposed to diffusion occupy within the social structure;

(2) to illustrate **recent** applications of diffusion models and theories in two key areas of sociology, social movements and social organizations;

(3) to describe conditions for testing new hypotheses and conjectures that invoke diffusion processes, and take advantage of the richer formulations alluded to before. These conditions are strict, difficult to satisfy, and have implications for issues ranging from data collection to utilization of estimation procedures. I argue that unless these conditions are met, we will not be in a position to identify diffusion processes from

among other processes producing similar observable outcomes.
(4) to argue that until very recently at least, applications of diffusion models in demography, mainly in the study of fertility but also in the study of mortality, have not incorporated the theoretical innovations identified in (2), and have not adhered to the formal conditions identified in (3). Under these conditions these applications are unlikely to be of much help to improve our understanding of social and demographic phenomena.

The organization of the paper is as follows: Section II defines the basic model of diffusion in s ociology. Sections III through VI deal, in turn, with each of the tasks mentioned before, while Section VII contains some final thoughts and conclusions.

II. THE BASIC MODEL OF DIFFUSION IN SOCIOLOGY

In this section I show that sociological theories of diffusion have evolved from fairly simple propositions regarding average or aggregate behavior into complex formulations about how individuals define preferences and make decisions to realize those preferences. The main point of this section is to argue that: analytically useful diffusion models require theorizing about social structures, about the positions that individuals occupy in them, about individual decision-making processes that accompany adoption of a behavior, and about the constraints these individuals face. I conclude that it is unilluminating to confront diffusion theories with competing explanations that regard behaviors as responsive to "structural" factors, such as socioeconomic positions or social class membership, as if diffusion processes did not require or could proceed independently of structural factors that characterize the environment where individuals act and where behaviors take place. Similarly, it is misleading to cast diffusion models or theories against alternative ones on the grounds that the latter are usually erected on a foundation of assumptions about rational actors and well-defined decision-making process, as if diffusion processes did not require making assumptions about preferences, costs, and a rational calculus. Well-defined diffusion hypotheses and models must be built on assumptions about social and economic conditions that constrain individual

actors' preferences and resources, and rely on these assumptions no less than alternative hypotheses and models oftentimes pitted against them. This is not to say that diffusion models or theories do not have a specificity of their own. They do, and it will be the task of the next sections to identify what this specificity is. In the end, however, my message is somewhat pessimistic because the conditions for identification of a diffusion process from observables are fairly hard to meet, much harder than what is normally implied in traditional applications of diffusion theories and models to sociological and demographic analyses.

1. Diffusion explanations and structural explanations

"Structural" explanations of behavioral changes seek their cause in the alteration of preferences and opportunities that result from either changes in positions that individuals occupy (individual social mobility) or from reshuffling of resources associated with a given social position (structural social mobility or redistribution of wealth). Diffusion explanations or models, on the other hand, attempt to identify a cascading mechanism that leads to cumulative adoption of behaviors by some individuals, even while their social position, or the resources associated with them, change only trivially or remain unaltered. In diffusion models, the behavior 'spreads' and is adopted by individuals irrespective of their socioeconomic positions, even among those whose social or economic positions are **hypothetically** associated with cost-benefit calculations that do not necessarily require the new behavior. Adopting the new behavior occurs as a result of reevaluation of one's own choices **in light of other people's behavior**, not as a strategic response or accommodation to a realignment of resources associated with one's social position in the social system. To use the terminology Coleman coined for the study of collective behavior (Coleman, 1990), diffusion models are built on the central idea that, individuals **transfer partial or total control of their own behavior to others**. As I will show later, this requires a decision process as complicated (or uncomplicated) as the ones that are normally associated with structural explanations.

Diffusion processes do not always involve adoption of new behaviors. In fact, they may include abandonment of a recently adopted behavior or resistance to change. For example, it has been observed that, contrary to expectations, class-based political alignments do not always take hold at a pace that is commensurate with advances of industrialization. Instead, traditional political allegiances, based on language or ethnic identities, may remain dominant long after industrialization has created the 'structural' conditions for class-based politics. This type of phenomenon has been studied widely in political sociology to understand the stubborn persistence of non-class based allegiances and ethnic enclaves (Hechter, 1975). In these cases observed individual political behavior (voting behavior) is at odds with what is expected by virtue of individual's position or ranking in the social system. Failure of individuals to act according to class positions--an expectation derived from a 'structuralist' explanation of political behavior--occurs as a result of adherence to practices that were consistent with positions occupied prior to the social and economic transformations that accompanied industrialization. What is diffused or adopted here is the individual resistance to act according to class based principles (the new behavior), and the reinforcement of traditional political alignments (the old behavior). If political sociologists had access to information on collective protests against British rule, rather than just to voting behavior, they should observe waves of protests extending across and confined within the boundaries of the British fringe, much as they observe waves of protests in the US during the sixties (Myers, 1997).

Similarly, we know all too well that fertility decline in Europe did not always follow a trajectory consistent with social and economic transformations that accompanied industrialization. Instead, the course of the decline revealed a marked tendency to proceed along or be halted by ethnic, language, and religious boundaries. The resulting geographic and territorial clustering of fertility levels and patterns has been construed as evidence against a structural explanation of fertility decline, and as support for the

hypothesis that fertility changes were strongly associated with ideational or cultural changes and diffusion mechanisms.[1] The existence of a clustering of fertility changes along cultural lines could be evidence of diffusion of either a new behavior (adoption of contraception and a low fertility norm) in areas where fertility declined below what one would expect given levels of industrialization and urbanization (structural changes), or of resistance to the new behavior (rejection of birth control and adherence to a high fertility norm) in areas where fertility remained higher than expected given levels of industrialization and urbanization.

The foregoing examples share two features. The first is that in both cases we establish a contrast between an explanation that infers an expected behavior from a reading of individual socioeconomic positions (the 'structuralist' explanation) with an alternative explanation that infers a pattern of expected behavior from the likely adherence of actors to ethnic, religious or cultural prescriptions or beliefs shared by others in the same community, including individuals belonging to different social classes or occupying different socio-economic positions. In the latter case, the likelihood of adherence to prescriptions increases as a function of others' adherence to it (or others' resistance to the novel behavior). The definition of what is included in 'others' is and must be a key element of the theory, as should the identification of the mechanisms that reproduce efficiently adherence to prescriptions and beliefs.

The second common feature shared by these two examples is that the structuralist or socioeconomic explanation and the diffusion explanation offered to account for the phenomena rest on the idea that individuals are decision-makers, acting in uncertain environments, sorting through limited information on prices, utilities, constraints, potential outcomes of alternative behaviors, elucidating their own preferences, and

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[1] An important idea that I will defend later is that one should not conflate the notions of cultural or ideational explanation with the notion of diffusion. They are simply not equivalent and many confusions could be avoided if we kept them separate.

ultimately taking some course of action. But, whereas investigators are normally careful to produce a thorough definition of the decision process associated with the structuralist explanation, they all too often fail to specify the decision-making process associated with diffusion, to the point that this appears, in many instances, as a result of passive contagion and the irrational or at least a-rational adoption of a behavior. This is a situation not unlike the one found until recently in the study of collective actions that could be explained only through recourse to the irrationality of actors (Coleman, 1990). The exceptions to this lack of attention to decision-making processes embedded within diffusion are precisely the most recent studies and formulations of diffusion processes in sociology, economics, and demography (Montgomery and Chung, 1994; Montgomery and Casterline, 1993; Valente, 1995; Marsden and Friedken, 1993; Burt, 1987).

Lack of theoretical specificity is not the only problem we face as we try to identify diffusion processes. In fact, most of the evidence produced in sociology and demography to distinguish between explanations based on diffusion arguments from those attributing the primary role to socioeconomic or structural changes, is carved out of aggregate, not individual data. Since the individual adoption process is never defined, the aggregate process is also ill-conditioned: there is rarely a way to determine what kind of aggregate evidence would one expect when the individual adoption process is left unspecified. This leads to the very generalized practice of using residual evidence or, equivalently, to infer the validity of a diffusionist explanation from the failure of the structural explanation: the explanatory power assigned to the diffusion argument is always directly proportional to the magnitude of the inconsistency between observed outcomes and those expected from a competing structural explanation. Handling only aggregate and residual evidence leads to one the central problems in this literature--both in sociology or demography--namely, the inability to identify the key process from observables.

2. The elements of an explanation based on diffusion processes

A classic definition of diffusion is the following: “(diffusion) is the process by

which an innovation is communicated through certain channels over time among the members of a social system. It is a special type of communication, in that the messages are concerned with new ideas" (Rogers, 1983). There are a number of essential elements contained in this definition: the innovation, the population of potential adopters, those who adopt, and the mechanisms through which adopters and potential adopters communicate with each other. The classical problem in diffusion models is to understand who adopts the innovation, and how fast they do so. Thus, Rogers (1995) distinguishes different types of adopters depending on how early during the process adoption occurs. To these groups one could add a category including those who never adopt, much as in social mobility we recognize movers and stayers. Delays in adoption or resistance to adopt are explained by inadequate information or by uncertainty about the results or outcomes associated with the innovation. As the process advances and more individuals adopt, and as the outcomes of adoption by others become observable, more individuals' resistance to adoption crumbles as the information is enriched and their uncertainty about risks, costs and benefits diminish.

Later in the paper I will introduce a slightly more complex definition of diffusion than the one just given. For the time being, I will focus on the more classic definition provided before to identify elements of a diffusion process that should be important in model building but that many applications seem to overlook. The simplicity of the definition given above is deceiving for it contains explicitly or implicitly a number of key elements that are important to identify at the outset**. First**, diffusion occurs through an individual decision-making process where there are costs and benefits (and implicitly preferences) associated with adoption (or its obverse, resistance to adoption), as well as information and ignorance about prices, costs, outcomes and alternatives. In their influential work on cultural transmission, Cavalli-Sforza and Feldman (1980) stress the important of decision-making as the factor that distinguishes cultural from biological evolution. Whereas the latter is driven by natural selection (or genetic drift), the former

is characterized by the influence of individual decision-making which may reinforce or offset the pressures of natural selection: "In cultural evolution, however, there is in addition [to natural selection] a second mode of selection, which is the result of the capacity of decision-making" (p. 10).

Diffusion only occurs because individuals decide to adopt after observing others do so, and after updating their information by including observed outcomes associated with others' adoption into their own decision-making process. There may be a variable number of stages in this decision-making process (Rogers, 1983), but what is important is that its core is an individual who is making cost-benefit calculations under uncertainty about whether to join others in adopting a behavior or resisting. A diffusion model rests on assumptions and imageries not dissimilar to the ones that prevail when, for example, we refer to individuals changing their fertility behavior as a result of socioeconomic changes that affect them (the so-called demand theories of fertility). The vast majority of applications of diffusion models in both demography and sociology neglect this very simple tenet of diffusion models: adopters and non-adopters are rational decision makers and adoption is the outcome of a rational decision-making process. These issues have been confronted head-on in only a handful of applications. For example, in a very recent study Montgomery and Casterline (1996) define three distinctive elements of a diffusion process, social learning, social influence, and institutional constraints, which operate to determine and shape individual decision-making about adoption of behaviors. Similarly, Erbring and Young (1979) and Marsden and Friedken (1993) carefully elaborate on the types of social relations that are relevant for processes whereby behaviors of one individual are affected by consideration of behaviors of other individuals belonging to the same group or social system. Coleman's study of collective action and those involving or generating trust reveals the fundamental elements of the decision-making process on which every diffusion process depends (Coleman, 1990). Even in the study of organizations and organizational diffusion (DiMaggio and Powell, 1991) there is explicit

consideration of actors who imitate organizational features adopted by successful organizations as an explicit device to minimize uncertainty.

Second, given conditions defining their preferences and opportunities, individual decision makers may be more or less resistant both to adopt innovations and, if they adopt, more or less reluctant to jettison the innovation from the menu of practices and behaviors they normally employ. That is, after one accounts for all elements entering in the decision to adopt or to resist, there might be individuals who are more (less) risk averse and adopt more (less) easily than others. These will be forerunners (laggards) in the diffusion process (Rogers, 1983). As stated by Cavalli-Sforza and Feldman, "It seems very likely, *a priori,* that there is variation between individuals in their capacity both to learn of an innovation and to decide for adoption. Many factors contribute to such variation, including social and economic stratification, geographic conditions such as means of transportation, availability of communication networks, and, last but not least, individual differences in the behavioral characteristics that govern both awareness and eventual adoption" (Cavalli-Sforza and Feldman, 1980: p. 39). This acknowledges that after accounting for a number of social and economic factors, we are likely to face the existence of 'unmeasured heterogeneity' or the inability to include all elements that contribute to the individual's decision regarding the innovation. It is a concept analogous to frailty in the analysis of mortality and induces the same empirical patterns: as individuals who are more resistant to adopt become a larger fraction of the pool of non-adopters, the overall risk of adoption will tend to decrease. But this is not a reflection of a risk profile of adoption that decreases over time. Rather, it is an artifact of the changing composition of the pool of non-adopters as the process progresses over time. To my knowledge, the traditional literature on diffusion processes in sociology or demography has not addressed the problem created by the unmeasured resistance to adoption, except insofar as the study of forerunners and the conditions that determine their appearance is

indeed a way to identify factors influencing unmeasured resistance.[2] But, in general, we neglect the issue altogether. This practice is explained by one of two factors: either the assumption is made that all relevant factors were well measured (including those affecting awareness and propensity to adopt), or the focus of attention is on aggregate patterns of adoption. It is only recently, mainly through the influential work of Granovetter (1978) and Valente (1995), that the concept of individual (or group) thresholds has been introduced as a way to handle the problem, but still without deriving the full consequences for model-testing. Later I will provide an interpretation, by no means unique, of unmeasured resistance to adoption.

Equally important for the successful progression of diffusion are processes that may undermine continued practice of the new behavior. To the extent that these acquire some dominance, individuals are more likely to abandon the new practice or behavior some time after adoption. Despite the fact that this is a rather key part of a diffusion process, it is rarely mentioned and almost never explicitly modelled or studied.[3]

Third, the decision-making process underlying adoption of new behaviors occurs within a social structure composed of formal and informal elements. Individuals occupy positions within these social structures, perform certain roles, and are connected formally and informally to a number of other individuals within it through relations of authority, functional rapport, respect and trust. They adhere to values and norms that shape

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[2] An interesting example of a case study of forerunners is Livi-Bacci's description of apparent practices of fertility controls among elites and other selected social groups in Western Europe (Livi-Bacci, 1986).

[3] Potter (1998) addresses the problem explicitly though devoting more attention to what he calls 'pernicious aspects' of social interactions that end up imparting inertia in the adoption of contraceptive technology and locking populations into a restricted menu of contraceptive choices and less to mechanism of outright abandonment of an adopted practice. Sinding and Mason's paper (1998) also addresses the problem of rejection and, finally, Kohler's new work (Kohler, 1996) provides an opportunity for rigorous formal treatment of it. This problem has been better formalized in the literature on collective violence (Myers, 1997).

preferences, constrain the field of feasible behaviors, and alter the information they may receive about prices, utilities, and ultimately about what others are doing. Despite the fact that oftentimes it is difficult to tell so from actual empirical research involving diffusion models, diffusion processes are affected by the social structure of systems within which they are occurring. Social structures determine the content and shape of the repertoire of feasible behaviors ("is the behavior within the realm of conscious choice?"), individuals' preferences ("is the behavior advantageous at all?"), individuals' resources ("can individuals adopt at low costs?"). The sentences within quotes describe Coale's well-known desiderata for fertility change (Coale, 1973; see also Lesthaeghe, 1977) and could be utilized equally well by an explanation resting on diffusion as in alternative mechanisms involving adjustment to structural changes. I will elaborate this in sections V and VI.

The importance of social structure appears to weigh more heavily when the diffusion process is suspected to be under the control of internal sources rather than external sources of diffusion. However, even the idea that external sources of diffusion have an impact independent of individuals' position in the social structure is acceptable only as a tool to render the algebra of models tractable, but is woefully inadequate for analytic purposes. Some of the best original work on diffusion processes emphasizes that social diffusion is an analytically sterile construct if not cast against a social structure: "It is as unthinkable to study diffusion without some knowledge of the social structure in which potential adopters are located as it is to study blood circulation without adequate knowledge of the structure of veins and arteries" (Katz, 1961 cited in Rogers, 1983: p. 25). Similarly, in their influential study on use of hybrid corn among farmers in two Iowa communities, Ryan and Gross (1943) argue that it is the social structure that may explain the delay with which certain technologies are adopted. They reason that, if all individuals act as rational actors, adoption of an advantageous technological innovation must occur instantaneously and simultaneously. Delays and lags in the process and the

emergence of laggards in the population of potential adopters can only be explained by institutional constraints and by sociocultural and psychological factors that influence the diffusion process. In this case, social structure is taken to be an obstacle rather than a facilitator. Structure accounts for the slow progress of diffusion rather than diffusion undermining the constraints fabricated by social structures.

Although emphasis on the importance of social structure for diffusion processes is hardly new, and even despite the fact that there are good examples demonstrating careful attention to social structure (Rogers and Kincaid, 1980; Coleman et al., 1966; Burt, 1987), it has rarely been **systematically** incorporated into actual empirical research. It is only recently that sociologists interested in diffusion have begun to pay close attention to it and account for it explicitly in the formulation of models. In a very recent paper, Strang and Soule make the point that while diffusion studies inquire about how practices spread, they also "provide an opportunity to locate and document the social structure, where we consider how patterns of apparent influence reflect durable social relations" (Strang and Soule, 1997; p. 1). Furthermore since these models involve individual decision-making subjected to constraints imposed by a social structure, they may "...verge on the one hand towards models of individual choice, since diffusion models often treat the adopter as a reflective decision maker....[or] verge on the other [hand] towards a broader class of contextual and environmental processes, where conditions outside the actor shape behavior" (Strang and Soule, 1997; p. 2).

Fourth, once innovations are adopted they could be abandoned and replaced by other technology, instruments or behaviors. Thus, in addition to understanding who adopts and how fast they do so, models of diffusion should specify the obverse process, that is the persistent use of the innovation. This aspect of a diffusion process is of importance in applications to social behaviors that are inherently reversible or unstable. For example, participation in mass protests usually involves increased risk of participation followed by increased risk of withdrawal from the pool of protesters.

Withdrawal from protest is as much a diffusion process as is participation in it (Myers, 1997), and could be triggered and encouraged by external reprisals. Discontinuation is also relevant for situations where what is at stake is the adoption of an innovation such as contraception. Contraceptive discontinuation is an obvious illustration that has become a staple of empirical studies of contraception, but so is the possibility that certain groups may adopt contraception and then abandon altogether the very ideal of family limitation. If one succeeded in providing a convincing explanation of fertility decline in Western Europe entirely based on diffusion arguments, it should be clear that we should also explain why the decline turned out to be irreversible. Although this seems an obvious requirement, I have seen no systematic evidence indicating that the issue has been raised, much less treated systematically (for an exception see Kohler, 1996). Note that this is not a requirement that applies to explanations invoking adaptation to new social and economic conditions. Whenever possible and non-trivial then, an ideal diffusion model ought to specify the conditions for the persistence of adoption.

Fifth, the social and economic environment may be modified by the process of adoption itself, and may involve feedbacks accelerating or retarding the process. The adoption of some computer technologies, for example, becomes unavoidable once a critical mass of users has adopted since the incentive structures for all users is altered, becomes more favorable for adoption of the technology, and creates niches for the introduction of even newer technology. The adoption of operating systems for PC's proceeds in this fashion, with software production being the element that induces interdependence between consumers in the market. Similarly, changing prices of a product induced by partial adoption of a technological innovation in agriculture will alter the elements that enter into the calculus of non-adopters (Ryan and Gross, 1943; Hagerstrand, 1967). Adoption of organizational features such as civil service reform may begin to occur for reasons that have to do more with the establishment of legitimacy of the practice rather than with associated increases in efficiency (DiMaggio and Powell,

1991). Adoption of a practice may accelerate as organizations that have not yet adopted find it advantageous to mimic what others have done successfully as a way to sharpen their competitive edge in the new environment created by a handful of forerunners (Fligstein, 1985). DiMaggio and Powell's 'mimic processes', whereby organizations imitate what other organizations do, refers to processes whereby the linkage between a practice and its net benefits is subject to less variability, but also to processes where the institutional environment is so changed by early adopters that adoption simply becomes more cost-effective. Only the latter is an example of endogenous feedback.

Similar processes may be at work in fertility behavior: forerunners who first adopt fertility control not only generate an environment with reduced uncertainty for others to follow, but may also create emulation conditions. This can happen, for example, if with fewer children they are able to support higher or better educational standards and if, in the long run, this enhances their power and prestige. To the extent that this is so, non-adopters pursuing power and prestige will be better off if they imitate fertility limitation. As the process evolves, the institutional context to satisfy the demand for more and better education evolves, thus changing the context where fertility decision-making is taking place.

In the case of organizational adoption, the pool of means to attain some ends is changed by adoption of newer procedures or strategies, and so is the ranking of those that are preferred among all organizations in the field, not just those who initially adopt. In the case of fertility, the connection between fertility limitation and power and prestige via children's education converts the adoption of contraceptive behavior from an oddity to a useful and productive behavioral strategy.

In these examples taken from sociology of organizations and fertility, there is endogenous feedback since the spread of the behavior changes the elements that enter into the decision-making process of everybody, including non-adopters. Surely, there must be considerable empirical variability in the lags with which the feedback operates,

and in their actual significance for individual decision makers. Thus, endogenous feedback need not be an inherent nor a uniform characteristic of all diffusion processes. But, when it is, it will alter individual probabilities of adoption for individuals who have not yet adopted at a certain time in the process.[4]

The combination of some of these five elements of a diffusion process may produce a lightning fast spread of innovations. By the same token though, particular constellations of the elements may lead to excruciatingly slow adoption, to innovation processes that begin rapidly but then taper off without ever reaching near-saturation, or to those that fail altogether and are then relegated to the pool of diffusion processes that we will never be able to study.[5] An immediate corollary of this inherent variability is that it is not necessarily correct to infer the existence of a causal mechanism (diffusion mechanisms versus structural mechanism) only from observation of the relative speed with which a behavioral change occurs. It is as much an error to believe that when a process of behavioral change is quick and swift, it must have been due to diffusion as it is to think that no diffusion process could be responsible for slow changes. The observed rate of change in the prevalence of a behavior **by itself** will generally be of limited help to identify a diffusion process since the effects of the basic elements of a diffusion process may lead to outcomes that can also be produced by mechanisms not associated with diffusion at all. Rapid rates of change in a behavior in the absence of changes in structural condition **may** be a reflection of diffusion but surely should not be taken as *prima facie* evidence of its existence or predominance.

These five elements need to be taken into account when formulating a diffusion

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[4] See the paper by Durlauf and Walker (1998) for a formal treatment of some aspects of the endogenous feedback mechanism.

[5] The selection issues arising from devoting overwhelming attention to diffusion processes that more or less succeed in taking hold while neglecting those where diffusion never takes off or dies out shortly after its onset are presumably quite important but, to my knowledge, have not been seriously studied.

model. But, needless to say, they not always are. In Section IV I show that this oversight leads to shortcomings in sociological applications. In section V we will return to these elements and use them to define more formally what a diffusion process is, and what are the mechanisms through with it operates.

III. DEVELOPMENT OF DIFFUSION MODELS IN SOCIOLOGY

In this section I discuss developments in the formulation and application of diffusion models in sociology. I start with early models that mimic those used for the study of the spread of diseases and focuses on narrow aggregate outcomes. I then discuss some of the most novel applications in the areas of collective action and organizations.

1. Early studies and formulations

The main territory of diffusion theories and models is the innovation. Innovations by their very nature require communication and information for adoption. They are also risky since their outcomes are for the most part uncertain or unknown, thus requiring an agent engaged in a decision-making process. It is not surprising then that diffusion processes have been mostly used to study adoption of innovations. The most influential works include Ryan and Gross's (1943) analysis of the diffusion of hybrid corn, Hagerstrand's (Hagerstrand, 1967) investigation of the diffusion of TB tests in Sweden, Coleman et al.'s (1966) study of the adoption of tetracycline among Midwestern doctors, Katz and Lazarsfeld's (1955) celebrated formulation of the two-step flow of influence process, and Rogers and Kincaid's analysis of contraceptive behavior (Rogers and Kincaid, 1980). The main goal of all these studies is to assess the effects of the mass media, the degree of influence of individuals located at the top of the community hierarchy (agents of change), and the relative contribution of interpersonal interactions within the boundaries of the community where the innovation is spread. In all these applications, the empirical evidence gathered to demonstrate the existence of diffusion includes individuals, their characteristics and interactions. In only one of these studies was the evidence restricted to observation of aggregate outcomes such as proportion of

adopters. With the exception of the work by Hagerstrand and Ryan and Gross, these studies placed emphasis on interpersonal relations and channels of influences as the mechanisms fostering or impeding diffusion. In this sense they anticipated some of the most useful work on social influences in general and diffusion in particular (Bandura, 1986; Moscovici, 1985; Marsden and Friedkin, 1993; Erbring and Young, 1979). However, besides this handful of very consequential empirical studies of diffusion, the bulk of the tradition in the area rests on the formulation of models that are testable with aggregate information about behaviors, such as the total numbers of adopters or proportions of a population who are adopters. These formulations mimic contagion models for the spread of disease and have the unfortunate consequence of portraying the social diffusion process as one where individuals are either passive carriers of information and innovations or passive 'susceptibles', rather than actors engaged in real interactions. Furthermore, these models almost always require the rather strong and frequently unacceptable assumption of temporal and spatial homogeneity. Stochastic versions of these early models make room for some types of heterogeneity, but have proven to be mathematically intractable and have stimulated little empirical research (Bartholomew, 1982; Bailey, 1975). New deterministic formulations of contagion models with explicit consideration of limited types of social heterogeneity have had little impact in sociological analysis (Anderson and May, 1992; for an exception see Morris, 1993).

As shown in the review by Mahajan and Peterson (1985), conventional formulations of aggregate diffusion incorporate external sources and social interaction among individuals, and result in testable hypotheses about the progression of the number or proportion of adopters in the population o ver time. The classic representation with a logistic cumulative distribution (the so called 'S-shaped' curve of adoption) is, in fact, a very general result, and holds up well under a number of formulations. The reasoning behind this formulation is that, if diffusion is mediated by interactions between

individuals, it must be the case that the rate of change in the proportion P(t) of adopters is given by:

$$\frac{dP(t)}{dt} = [r_o + r_1 P(t)] (A - P(t)) \qquad (1)$$

where A is the ultimate fraction of the population that will adopt, r_o is the number of new adopters that results from interaction with external forces, and r_1 is the number of new adopters that results from interactions between adopters and potential adopters in a small interval of time, dt (the 'diffusion yield' of social interaction). When r_o is 0 we have a simple case of pure social interaction effects, and when r_1 is 0 we have a case of pure external effects and no social influence to speak of. This formulation does not distinguish between types of external sources nor between classes of social contacts as all interactions are considered the same, and all are thought to be equivalent in terms of their 'diffusion yield'. Admittedly, one can complicate the formulation in a number of ways (see Mahajan and Peterson, 1985) to include the influence of several external sources and, more generally, to represent limited social heterogeneity. For the most part these modifications preserve the main advantage of the logistic process, simplicity, but do not supersede its main shortcomings, a result of the fact that the structure modelled is not complex enough to permit us to distinguish empirically among alternative processes. For these reasons, improvements in models that focus on aggregate processes are unlikely to generate significant progress. Thus, logistic and related aggregate representations of diffusion processes are increasingly relegated to the camp of fragile descriptions.[6]

About a decade or so ago, sociological analyses of phenomena of diffusion models

[6] An important aspect of the weaknesses of these models to identify underlying processes is that researchers who employ them usually assess the fit between observed and expected outcomes by examination of cumulative occurrence (proportion of the population who has adopted, for example). It is well known that a good fit of a cumulative distribution can conceal complete failure to predict associated densities (frequencies of new adopters during a small time interval).

moved in two different directions, away from conventional contagion models. The first and, as suggested above, perhaps least promising route was to reformulate logistic models to enrich the complexity of the structure being represented. The second and most promising was to reshape the object of study: rather than targeting aggregate parameters, such as the overall adoption rate, researchers began to focus on individual processes. This type of model shifts attention toward individual behaviors and individual adoption, and redirects attention toward actors who are decision-makers, the processes of social influence that shape decision-making and, lastly, to the constraints to which these are subjected. The models eschew discourses about aggregate trajectories and formulate conditions for individual decision-making that underlie a diffusion process. These models enable the researcher to fully incorporate complexities of the adoption process itself (inter-agent communication, external sources, barriers, agents of change, etc.), and the social conditions of interaction between actors who are adopters and potential adopters.

2. New models for aggregate outcomes: examples from collective action

An important step forward in the formulation of new diffusion models is the work on collective violence carried out by Pitcher, Hamblin and Miller (1978). Their formulations were part of a more general effort to produce fruitful applications of diffusion models (Hamblin, Jacobson and Miller, 1973). The main notion behind their model is that the observed expression of collective violence depends on both imitation and inhibition processes determined by outcomes of prior events. Individuals learn from others' behavior, including those participating in acts of violence, and those repressing violence, and are able to understand when and how collective violence occurs but what tactics seem to work best. As in all other aggregate diffusion models, however, it is the number of past events on which decisions to adopt violence depend. Similarly, individuals are assumed to be homogeneous with respect to the relevant behavior (or characteristics determining the behavior), and events in the past influence current events

in like manner (there is time homogeneity of outcomes). With these simplifying assumptions the authors formulate a model for the rate of change of acts of collective violence **and** the rate of change of repression acts. The model rests on two equations representing respectively the rate of new acts of violence and the rate of inhibition of acts of violence:

$$\frac{dP(t)}{dt} = a\ \frac{P(t)}{I(t)}$$
$$\frac{dI(t)}{dt} = b\ I(t) \qquad (2)$$

where P(t) is the cumulated number of violence at time t and I(t) is the cumulated number of inhibited acts of violence. The algebra to solve for P(t) is transparent but tedious and results in the following function:

$$P(t) = P_0 \exp(d\ /\ b)\exp(-d\ /\ b)\exp(-b\ t) \qquad (3)$$

a model that represents the cumulated number of events (acts of violence), P(t), through a Gompertz distribution function. A Gompertz function is better suited to fit processes that lack the symmetry embedded in a logistic formulation, namely, those where the adoption process drags on through initially long and protracted stages before finally taking off. Asymmetry suits well most process of collective violence studied by Pitcher et al. But although this curve fits the data better (see footnote 6), the most important innovation introduced here is that the aggregate model is derived from an ideal individual decision-making process whereby actors decide whether to participate in, abandon or avoid altogether acts of violence.

Modifications to the model introduced by Pitcher et al. that include an explicit definition of the growth process of repressive acts leads to an even better representation

of the trajectory of collective violence (Myers, 1997). Not only does this formulation enable us to model the decision-making process of individuals who are potential adopters of the behavior but also the responses of those who are charged with the function of preventing those actions from occurring at all. The idea of formulating jointly two diffusion processes, one which fosters the behaviors of interest and one that inhibits their realization, should be of interest to those studying social process where the innovation, such as fertility control, may generate resistance on the part of central authorities or among influential members of the community (such as community elders, the church, provincial authorities, or even the state). This is, in fact, an elegant way to treat one of the elements of the diffusion process, namely, the phenomenon whereby individuals cease to embrace or adopt a behavior (see section III.2). Yet, although from the point of view of the theory of collective action this is much richer material, it continues to lead to a model for the aggregate number of collective acts of violence. And this is its main limitation.

A second type of diffusion model estimated with aggregate data relies on a more nuanced representation of how individuals experience transitions from the state of non-adopter to the state of adopter (Rosero-Bixby, 1991; Rosero-Bixby and Casterline, 1993, 1994). Although the models are estimated from aggregate information (pooled cross-section and time series data on mean levels of fertility), its very nature (a close kin of compartment models) make it suitable as a representation of individual processes. Thus, the linkage between aggregate outcomes and individual behavior is more explicit here than what normally is in conventional diffusion models or even in the modified diffusion models for collective violence reviewed before. It is from this characteristic that the model derives its superiority since it facilitates a richer formulation of the process than some of the models proposed by Pitcher and colleagues. The disadvantage of the compartment model formulation is that it is somewhat difficult to estimate from data normally available to us and frequently, as with other aggregate models of the same type,

they do not provide enough evidence to determine whether a diffusion process or something else explains the behavior under study (see, for example, simulations carried out in Rosero-Bixby and Casterline, 1993).

3. Models of social influence in collective action and organization theory

Somewhat paradoxically, an important part of the drift toward individually-based models of diffusion occurs within areas traditionally reserved to the study of macrosocial processes, such as social movements and social organizations. In what follows I review illustrations of the application of new models of diffusion in these two areas of study.

a) Collective action

Initially, studies of common forms of collective action (protests, lynchings, etc.), sprung from the idea that individual participation in such movements is a result of spontaneous and irrational imitation of anti-social behavior (LeBon, 1897; Kornhauser, 1959). A contagion process was thus clearly justified as the best representation. This was replaced in the late sixties and early seventies by theories with an economic foundation which viewed collective action as the result of an atomized, individual decision-making process within a given social context and social environment (Olson, 1965). The overwhelming preoccupation in these formulations was centered in the so-called free-rider problem: to the extent that collectivities did not suppress the tendency of individuals to stay at the margins of actions, thus avoiding the costs of participation but reaping potential benefits, individual participation could simply be an irrational act. Reactions to Olson's atomistic theory came from many camps but mainly from those who saw the absence of a role for social institutions and social interactions as a fatal flaw. Soon new theories were built around conceptual frameworks emphasizing economic and demographic conditions external to the movement or action (Olzak, 1992; McAdam, 1982), facilitation, repression or channeling from the state or societal elites (Jenkins and Eckert, 1986; Tilly, 1978; Piven and Cloward, 1979; Pitcher, Hamblin and Miller (1978),

competition among protest groups (Tarrow, 1994), internal resources (Oberschall, 1989), and the role of internal social processes and heterogeneity among actors or groups of actors that frustrate or promote the smooth organization of collective action (Marwell and Oliver, 1993; Myers, 1997).

Perhaps the most interesting developments in collective action theory take place with the introduction of the idea that the decision to participate or not in collective actions may depend to some extent on conditions associated with the individual's position (individual costs, access to resources that facilitate action, etc.), and on the individual's interpersonal relations. A sophisticated paradigm emerges, one that poses the existence of a diffusion-like or social influence process mediated by 'the network structures of everyday life' (McAdam, 1995 cited in Strang and Soule, 1997). This change of focus is accompanied by a parallel displacement of the object of study: it is no longer sufficient or desirable to account solely for aggregate properties of the process (such as the proportion or number of protesters at a particular time, the rate of growth of protesters at the onset of the process, etc.) Instead, verification of richer theoretical specification of social influence requires to model individual decisions and individual actions (Myers, 1997; McAdam, 1995; Valente, 1995; Laumann et al., 1977, Granovetter, 1973).

It is incorrect to think that recent theories of collective action reduce the complicated processes that lead to collective action or determine its success or ultimate disappearance only to inter-actor diffusion or social influence processes. It is equally incorrect though to overlook the fact that it is the type of actor interactions and social influence processes in which one finds the essential features of collective action. This explains why, as indicated in the conclusion to a comprehensive overview of collective action theories and models, "...recent development in collective action models has centered on the problem of the interdependence of individuals within collectivities..." (Marwell and Oliver, 1993; p: 292). To be sure, there are other determinants and factors that should be examined, but without attention to social influence there is little hope of

fully understanding how collective action develops.

Not surprisingly, modelling actor interdependency in collective action requires concepts and tools that are suitable for modelling diffusion of behaviors. This is clearly evident in a number of recent models, from simple threshold models where actors' decisions at one point in time are affected by the prevalence of participation or adoption among other relevant actors (Granovetter, 1973; Marwell and Oliver, 1993) to more complex constructions where individuals' decision-making evolves as a learning process or as a function of decision-making among members of networks to which individual belong (Marwell and Oliver, 1993; Laumann et al., 1977; Marsden, 1981). Threshold models, social learning models and models of mutual influence are at the core of reformulation and representation of diffusion processes.

Coleman's propositions for new theories of collective action (Coleman, 1990) rest on an assumption about an individual decision-maker facing alternative action paths (adopting or not adopting a behavior also contemplated by other actors in the system). In doing so the actor considers what other actors are doing. Who the relevant others may be and the exact influence they may exert on any individual actor is possibly variable, and will depend on the actor's position within the collectivity, his channels of communications, and the type and frequency of relations to others. It is at this juncture where the investigation of contextual effects and its connections to social networks becomes strategic for understanding collective action. Since these are also the foundations on which new diffusion theories and models rest, it is worth to review them in some detail. To do so I will begin from and then extend the Erbring and Young's formulation of contextual processes.

According to Erbring and Young's important contribution (Erbring and Young, 1979), contextual effects only make sense if they lead to the specification of a model where actors' responses are a well-defined function of other actors' responses. Assume, for example, one is studying a response for individual I, y_i , and that we observe a vector

of responses **Y** containing the values y_1, y_2, ..., y_k, that is, all the information on responses for all relevant actors (1 through k) in the system. A proper model in Erbring and Young's formulation requires that we define **Y** as a function of a transformed vector of responses:

$$\mathbf{Y}=\alpha\mathbf{WG(Y)} + \quad \mathbf{X} + \qquad \textbf{(4)}$$

where **Y** is the observed vector of responses, is a vector of errors, **W** is a matrix of weights, **G** is a well-defined functional form, **X** is a matrix of covariates, and is a vector of associated effects. The central components in the model are **W** and α. The matrix of weights **W,** the 'contiguity' matrix, specifies the importance attached to other actors' responses by any one actor in the system. This matrix is what informs the nature of the network within which individuals participate, and the form in which their decision-making process influences all other members. The i^{th} row of the contiguity matrix contains elements that identify the 'weight' that individual I assigns to the influence of the response of another member of the system. We could think of these quantities as if they measured the degree of 'infectiousness' of other members of the system (if they are infected) or social distance. In most cases one normalizes these quantities so the sum over all j is identical to 1 (Marsden and Friedkin, 1993). Clearly, the definition of **W** will vary depending on the mechanisms that generate or govern social influence. As they strive to understand achievement or aspirations among students of various classes in a school, Erbring and Young (1979) express thus the nature of the dependency of **W** on various social processes: "...in the case of a contagion process, contiguity may be based explicitly on the amount of face-to face interaction specific to each pair of students; whereas in the case of comparison or competition processes, contiguity may be defined as fixed and equal for all pairs of students in a given classroom and zero for all pairs of students of different class rooms ..." (Erbring and Young, 1979; p. 411). In the following

examples **W** is defined in a number of distinct ways.

The parameter α reflects the strength of the 'feedback' from the group or collectivity. If this parameter drifts to 0, it is an indication that there is no social influence process affecting actors' responses, and that these are only a function of 'structural' characteristics (contained in **X**). One could generalize the formulation above by converting α into a vector, so that each individual in the system reacts differently to social influence and adoption by other members. In such a case, the elements of the vector are equivalent to what individual infectiousness would be in contagion models.

As a consequence of this formulation, a necessary condition to prove the presence of diffusion of responses within the collectivity is that α (scalar or vector) be significantly different from zero. To the extent that **W** is misspecified, however, the estimates of α will be biased and incorrect inferences about social influences will be drawn. Thus, our ability to identify processes of social influence rests heavily on a proper specification of **W**. It is the task of general social network theories to specify what the nature of **W** ought to be, and what modifications we must introduce in (4) to capture better the social context which is intending to represent. It is telling that social network theorists utilize formulations that are analogous, identical, or simple extensions of those proposed by Erbring and Young (see Valente, 1995; Marsden, 1998). I will show later that researchers in demography have also turned to variants of (4) to test new diffusion models for understanding fertility decline.

Note that model (4) is very flexible and that there are a number of variants that could be tested. For instance, suppose that **Y** represents responses at some time t and that **G** is the identity function. This simply means that there is a contemporaneous social influence. But if **G** is a lag operator so that **G(Y)** represents a vector of lagged responses, the model suggests that the process of social influence requires some time to be triggered and to exert significant effects on individual behaviors. Another useful extension is one where we postulate different matrices **W** for each lagged form of the vector of responses

to reflect the possibility that actors' mutual influence varies over time. Thus, for example, we can define a matrices $\mathbf{W}_1$ and $\mathbf{W}_2$ to be associated with vectors of responses of lag 1 and 2 respectively, $\mathbf{Y}_{(t-1)}$ and $\mathbf{Y}_{(t-2)}$. Similarly, while the response variable *y* can stand for a dichotomous indicator at time t (actor adopts a response or not at time t), it is probably more informative to follow a sequence of values for *y* over time. Rather than modelling an actor's response directly, one could choose to model the actor's risk of adopting the response at some time t, $\mu(t)$, as a function of a transformation of actual responses of other actors in the system, **G(Y)**. Finally, we could expand (4) to make **Y** a function not just of whether or not other responses have occurred but also of their observed outcomes. Thus, if adoption of a behavior by an actor could be classified as leading to "success" or "failure", we could augment model (4) as follows:

$$\mathbf{Y}=\alpha\mathbf{W}\,\mathbf{G(Y)} + \mathbf{W'G'(O)} + \mathbf{X} + \qquad \mathbf{(5)}$$

where $\mathbf{W}'$ is a modified contiguity matrix, $\mathbf{G}'$ a modified functional transform, and **O** is the vector of outcomes associated with positive (adopt) and negative (does not adopt) responses. In this model, evidence of diffusion or social influence must be retrieved from the estimates of α as well as from . And, as before, α and need not be scalar quantities but could be vector-valued.

In what follows I briefly discuss three examples of collective action research that make heavy use of these reformulations, and where the key empirical tests are designed to identify the magnitude and direction of effects of social influence. My objective is to highlight the adoption of model (4). The technical difficulties in estimating the model's parameters is the topic of section VI.

I. The spread of lynchings

The idea that certain types of collective actions rest on contagion or epidemic processes has been applied extensively to aircraft hijacking, insurrections, coups d'etat

and lynchings in Southern United States. In a recent article, Tolnay, Deane and Beck (1996) pose the question of whether or not lynchings were spatially contagious. More concretely, they ask: "Was the probability of mob violence in one region increased by similar outbreaks in other areas? Or, alternatively, did lynchings occurring elsewhere reduce the likelihood of subsequent lynchings?" (Tolnay et al., 1996, p. 789). In their analyses, the authors pay a great deal of attention to difficulties in identifying and separating contagion, epidemic or diffusion effects from a set of other ('structural') effects. To do so, they define explicitly the contiguity matrix, **W**, as one containing the reciprocal of the distance between any two units or actors (US counties). The value of **W** serves to properly weigh the influence of any county on a given county. They also define the function **G** as a matrix operator that transforms the observed responses *y* (frequency of lynchings in a given county) into an expected value (the expected number of lynchings in the county). The transformation depends on the relation between observed responses (frequency of lynchings in a county at a particular time) and a number of social and economic characteristics that proxy for the structural determinants of the frequency of lynchings. Thus the transformation **WG(Y)** proposed by the authors is a measure of the potential response (number of lynchings) of a county given the relevant environment of responses (expected lynchings in other counties). The final model includes controls for characteristics that proxy for structural conditions. Thus, the model used by Tolnay et al. is a subclass of model (4). As formulated, the model has one important shortcoming, namely, that as long as the contiguity matrix is built around spatial proximity, it leaves in the dark the mechanisms through which space facilitates or impedes social influence.

Surprisingly, their results reveal that diffusion or contagion is negative, that is, that "...net of other characteristics that have been shown to affect the likelihood of lynchings, the intensity of mob violence in nearby areas was found to be negatively associated with the corresponding frequency in other areas" (Tolnay et al., 1996, p. 811). This negative diffusion process is not altogether a rarity. It has been postulated as a possibility at least

in the analysis of forms of collective violence that trigger counter responses (Pitcher et al., 1978; Myers, 1997) and looms large in the analyses of movement and countermovement literature (Myers, 1997). Tolnay et al. interpret this negative diffusion process as one where the frequency of lynching in close neighboring areas satisfies the need for violence in a given location ("vicarious violence" hypotheses). A discussion of the adequacy of this interpretation is beyond the scope of this paper but it should be clear that the plausibility of the negative diffusion process as representation of how lynchings take place in space and time requires quite more that the confirmation of a negative value of α in model (4). Despite these limitations, however, the study illustrates the application of diffusion processes to the study of collective action, and it also hints at the possibility that diffusion can translate into negative (rejection of a previously adopted behavior) not just positive effects.

ii. The spread of strikes

A typical example of collective action is the strike. In their investigation of the frequency, duration and success of French coal miners strikes, Conell and Cohn (1995) postulate that there is a process of imitation whereby strikes stimulate other strikes and exert an influence above and beyond that of structural factors (such as bargaining conditions), successful strikes increase the rate of imitation, and structural conditions such as levels and types of unionization alter the process of strike imitation. Conell and Cohn formulate the following problem: to what extent is the frequency of strikes dependent on structural conditions such as workers' bargaining power and workers (and employers') organization, and to what extent are they responsive to an imitation process, whereby some strikes directly affect the probability of other strikes?

To answer this query the authors focus on strike behavior of French coal mining workers during the period 1900-1930. The existence of a diffusion process underlying the occurrence of strikes is identified via a hazard model for the risk of a strike in a coal mine located in a given geographic unit (French *département)* at any time t within the

chosen period. This risk is made a function of indicators of (a) the frequency, duration, trajectory and outcome of strikes in the same geographic unit and (b) indicators of 'structural' conditions representing other determinants of strike frequency (mostly invoked by mobilization theory). The diffusion or imitation process is empirically identified by examining the magnitude and direction of estimated effects associated with the indicators defined in (a) above. It should be noted that these indicators are exactly equivalent to the vector of responses **Y** (with time lags) and the contiguity matrices **W** and **W′** defined before. Although these matrices are only implicit in their analyses, it is not difficult to produce explicit expressions for them. These implicit matrices simply refer to the universe of unions within the *département* (the relevant system of actors) where the union at risk of striking (the actor) is located. One could, of course, criticize a number of issues in these definitions, and insist that the main contiguity matrices, for example, ought to include unions in adjacent *département.* Or, more importantly, that this and other choices about the matrices requires a better theoretical justification of what type of networks are effectively involved. For our purposes however, it suffices to note here that the authors put to the test a theory of collective action that invokes a diffusion-like process at the level of unions, and that the main test is via a formulation analogous to (5). Their key finding is that the rate of strike occurrence is strongly influenced by a diffusion or imitation process, not just by structural conditions, where the frequency of strikes in coal mines located within a geographic unit, their duration, and their outcomes affect the likelihood of occurrence in other coal mines located in the same geographic unit.

iii. The spread of trade unions

The last example of diffusion models in collective action regards the spread of trade unions in Sweden (Hedstrom, 1994). In this example, spatial relations are determinants of networks and network participation, and these are the main factors determining the outcome of a mobilization effort. The main thesis is that spatial

contagious processes exerted an decisive influence in the growth of the Swedish union movement.

Hedstrom's analysis starts from a critical review of Olson's theory and his unilateral attention to the free rider problem and consequent inattention to social networks that generate dependency between actors' decision-making. In the case of Swedish trade unions, the claim is that decisions to join the union movement are influenced not only by individual characteristics (the structural conditions) but also by the nature of their real or potential interrelations. The latter are in turn a function of spatial contiguity.

Hedstrom formulates a model for the hazard of a first union in a particular district. This model depends on (a) district-specific ('structural') factors that are likely to promote (inhibit) the formation of unions and (b) an indicator of the network exposure to union formation. Because the data are in discrete (year) periods, the author chooses to estimate a logit model, rather than a continuous time hazard model, of the following form:

$$\ln(p_{it}/(1-p_{it}))=\alpha_t + \quad _k (\ _kX_{ikt}) + \quad Z_{i,t-1}$$

where p_{it} is the probability that the first union will be formed in district I in the year (t,t+1), X_{ikt} is a characteristic k in district I at the beginning of year t, and $Z_{i,t-1}$ is the weighted sum of union members in other districts in the year before t. The weights chosen represent the inverse of the distance between district I and all others. Note that with these weights the variable $Z_{i,t-1}$ is a simple function of the product of a contiguity matrix and a matrix of lagged responses in other units or districts. Indeed,

$$Z_{i,t-1}= \quad _j \quad _{ij} \ n_{jt-1}$$

where $_{ij}$'s are the reciprocal of the distance between district I and district j and n_{jt-1} is the

total sum of union members in district j during the year (t-1,t). Thus this model has the classical form of other models for the spread of collective action. The evidence for (against) the existence of a diffusion process depends on the sign and magnitude of . Hedstrom finds strong evidence that the onset of a first union is dependent on the spatial networks even when other factors accounting for structural conditions and national trends are considered. His conclusion is that " ...the spread of information through the social or geographic landscape was of decisive importance for the formation of trade unions" and that " ...the spread of the Swedish union movement was caused by a combination of local factors operating within districts and a contagious process operating between districts" (Hedstrom, 1994, p. 1176). Or, translated in our jargon, the emergence of the Swedish trade union movements owes to both structural conditions as a well as to diffusion processes.

b) Organizations

The formulation of diffusion or contagion-like processes and their application in organizational analysis is relatively new. Its most explicit and fullest development takes place within the so-called new institutionalism framework. In what follows I discuss central elements in this framework and identify exactly where and for what purpose diffusion-like processes are invoked and utilized. I will attempt to show that these formulations are amenable to an analytic treatment very similar to those in collective action and that, as the latter do, they permit us to identify all of the definitional elements of a diffusion process.

Modern theories of organizations have long been intrigued by the diversity of organizations and preferentially sought to explain heterogeneity in organizational structure and behaviors. Yet, proponents of the new institutionalism reverse the question and ask instead about the startling homogeneity in organizational forms and behaviors. The latter position is, of course, a revisionist version of the classic Weberian bureaucratic perspective that seeks to explain organizational uniformity by invoking the need to adopt

rationalization to stay competitive and efficient. In some analyses of organization survival, the demise or failure of organizations is seen as a result of a selection process that weeds out the least competitive and efficient forms (Hannan and Freeman, 1977). This is only partially correct. According to the new institutionalism, homogeneity in the organizational field is a result of two processes one of which is driven by mechanisms of selection and competition (survival of the fittest or competitive isomorphism), whereas the other is one of institutional isomorphism. Its most distinctive characteristic is to be a result or consequence of adjustment in an environment populated by other organizations.

In an influential paper DiMaggio and Powell argue that competitive and institutional isomorphism are applicable in general but that different fields of organization may be more or less prone to one or the other of these two processes. Thus, they suggest that "[competitive isomorphism] is most relevant for those fields in which free and open competition exists. It explains parts of the process of bureaucratization that Weber observed, and may apply to early adoption of innovation, but it does not present a fully adequate picture of the modern world of organizations...As Aldrich (1979:265) has argued, 'the major factors that organizations must take into account are other organizations'" (DiMaggio and Powell, 1991:62)

There are three mechanisms of institutional isomorphism: coercive, normative and mimetic. It is only the latter that involves processes of social influence whereby organizations act and react to each other by adopting (rejecting) organizational features and behaviors, much as individuals are assumed to do in models of social contagion applied to collective action. Organizational mimicry could be construed as a diffusion-like process where the actual actors are not individuals but organizations themselves or key units within an organization.

The fundamental factor driving mimetic process is uncertainty. According to DiMaggio and Powell (1991) "...when organizational technologies are poorly understood (March and Olsen, 1976), when goals are ambiguous, or when the environment creates

uncertainty, organizations may model themselves on other organizations" (DiMaggio and Powell, 1991:69). Just as in the case of individual actors, there are organizations that innovate and others that follow and imitate. Innovations are sometimes the result of imperfect imitations by one or more organizations of features observable in another that result in a modified feature which turns out to be beneficial for organizations in a particular field. As in individual processes of social influence, organizations are more likely to imitate those organizations in the field perceived to be legitimate or successful.

Isomorphism attributable to mimetic process is more likely to occur under a variety of conditions characterizing the organizational field or the organizations themselves. Thus, for example, the less clear or certain the connections are between means and ends in an organization, the more likely the organizations will be to adopt behaviors or features from other organizations in the field. Similarly, organizations with ambiguous goals will tend to imitate successful organizations in the field. Imitation can also be the result of threshold effects in the sense that adoption proceeds at a faster rate once the total prevalence of the feature exceeds a threshold value.

The types of propositions of interest with regard to organizational mimicry are very similar to the case of collective action, and the new models introduced to falsify them are, not surprisingly, very similar also. I will illustrate the parallelism of propositions and models in two examples drawn from the recent literature in organizations.

I. The spread of the multidivisional form

The multidivisional form is a decentralized management organizational structure overwhelmingly preferred by those large firms that dominate the US economy. Under this organizational form "...firms are organized into product divisions and each division contains a unitary structure. There also exists a central office where the long range planning and financial allocations are located" (Fligstein, 1985, p. 378). This organizational form could be considered a central feature of firms within an industry that

adopt it. An interesting question is the following: what are the mechanisms that lead to the 'spread' of this organization feature? Is it simple adaptation to conditions set by the US market (of goods and employment), transportation technology and the legal environment or are there also imitation processes that trigger adoption of the form? This question was posed by Fligstein in an important article about ten years ago. To be fair, his effort was much broader for he attempted to discriminate between several alternative theories, all of which could account for the multidivisional form, but only one of them involves a mimicking process.

Fligstein explicitly models the adoption of the organizational feature with simple logit models, each of which is defined for one decade during the entire period under observation (1929-1979). Each logit model is for a dependent dichotomous variable that indicates whether the feature in a firm is adopted or not. Several independent variables capture essential features of the mechanisms postulated by competing theories (structural factors). He then includes in the model the percentage of firms in a given industry that adopted the feature before the beginning of the decade under observation. This is the variable that represents the crucial feature of a mimicry mechanism. For each period we have (t, t+10)

$$\ln (p_t/(1-p_t)) = {}_t\mathbf{X}_t$$

where ${}_t$ and $\mathbf{X}_t$ are vectors of covariates and effects for the period.

Although in a very simplified form, the model used by Fligstein is an example of the relational model for social influences introduced before. Indeed, the indicator of prevalence of the organizational form in a given industry is a summary indicator of the information contained in a lagged response matrix (**Y**) combined with the identity matrix as a contiguity matrix.

Fligstein's findings suggest that there is evidence suggesting that mimicry does

operate in the transmission of the multidivisional form. This evidence is not overwhelming as there is also support for the existence of other mechanisms of isomorphism. Inferences about the existence of a diffusion process, however, are somewhat weak, not just because the evidence is less strong than desirable, but also for two other reasons. First, as formulated the model cannot identify how exactly the imitation process proceeds, that is, it does not shed light on the micro-mechanisms (at the level of sections or units or single individuals in a firm) that sustain the imitation process. Second, there are a number of statistical problems that the author cannot resolve with the data available to him and they all involve issues of proper (inconsistent) estimation of parameters. These will be reviewed more thoroughly in the next section. Despite these shortcomings, however, Fligstein's work represents the first attempt to explicitly test DiMaggio and Powell's mimetic mechanism.

ii. The spread of women's ordination among U.S. Christian denominations

There are two related but distinct phenomena among a handful of significant transformations of 20th-century American religion. One is the increasing influx of women into the clergy. This trend parallels the increased influx of women in other professions, such as law and medicine. The second and distinct phenomenon is "the organizational-level phenomenon by which denominations adopted formal policies granting women access to all religious positions" (Chaves, 1996, p. 842). A graph of the percent of denominations granting women full rights shows a slow increase between 1900 and 1950 with an accelerating trend starting in 1960 and tapering off around 1990. Chaves, a researcher of religious organizations, believes that behind these trends there are diffusion processes. And although they may not be the only ones explaining the spread of the organizational practices, they could be important ones. Chaves formulates a number of questions. First, "why did some denominations begin to ordain so much earlier than others?" Second, "what are the differences between early and late adopters of this organizational innovation?" (Chaves, 1996, p. 842). The answer may be associated

with four types of processes: first, there might be structural conditions that generate organizational problems for which women's ordination may be a rational solution; second, environmental pressure toward full rights can be generated from within the organizational field; third, internal organizational features may retard or accelerate the practice and, finally, there might be a diffusion-like process whereby some denominations adopt the new practice as a way of resolving problems already resolved by other denominations. In this theoretical set up we have 'structural' explanations for the spread of the practice of interest which are subsumed under the first three mechanisms. There is, however, a fourth mechanism which refers to an imitation, mimicking or diffusion hypothesis whereby denominations will implement women's ordination simply as a response to the adoption of women's ordination by other denominations. As always, the question is how can we tell these competing hypotheses apart. It should be noted, however, that while strictly speaking only the fourth mechanism explicitly refers to mimicry, the third cannot be considered as a separate structural explanation. To the extent that the factors involved in it retard or accelerate the process of adoption they should be an integral part of the diffusion process. A similar argument applies to the third explanation: if by 'pressure from within the organizational field' we understand the organizational environment as affected by the adoption of the new feature, then this refers to a feedback mechanism and should be part of what the diffusion process triggers.

The novelty in Chaves' analysis is the procedure he proposes to assess the validity of the diffusion hypothesis. His main strategy is to use a hazard model for the risk of extending full rights to women, tracing the process for about 100 denominations within the period 1955-1987. The hazard model is a piecewise logistic model that includes a number of variables, each of which represents the most important dimensions of the four hypotheses being considered. To test the effects of diffusion, Chaves suggests the use of a time-varying covariate that "indicates for each denomination in each year, the proportion of that denomination's inter-organizational ties that are to denominations that

already have begun to ordain women." This variable is a member of the family of variables that could be generated from the more general expression involving the matrices **W** and **G(Y)**. Note that the construction of this variable requires full knowledge of the network connections of each and every one of the denominations for every year in the analysis. This represents a much finer elaboration of the social networks than we found in other applications. However, Chaves does not suggest a weighting scheme whereby some connections would have unequal influence.

The results of the analyses are unmistakable: the evidence overwhelmingly points in the direction of a diffusion process though some institutional (structural) characteristics are also important. Regrettably the author does not fully develop the consequences of his analysis, and we are left in the dark as to the relative importance of the mechanisms involved. Despite this limitation, this study is very valuable for it demonstrates how to justify theoretically and then specify empirically a properly defined contiguity matrix, one that does not rely on coarse notions about social proximity (such as spatial proximity).

IV. NEW MODELS OF DIFFUSION: PROBLEMS AND UNRESOLVED ISSUES

The discussion in Section III and the review of recent sociological applications in Section IV, provide a set of elements for identifying essential characteristics of diffusion models, and for testing propositions that seek to identify their relevance in empirical cases. Unlike conventional diffusion models, the new models applied in sociological analysis make explicit the mechanisms through which diffusion occurs and provide an environment for testing their empirical relevance.

In this section I will identify the main characteristics of these models, establish the advantages gained by adopting them, note important shortcomings, and discuss possible improvements. Throughout, the discussion is focused on the following query: how can we identify a diffusion model, that is, how can we tell it apart from altogether different

mechanisms? This discussion will furnish a 'golden' standard which will be used in section VI to assess diffusion models applied to demographic problems.

1. A simple representation of diffusion processes

In light of our previous discussion we introduce a modified version of the definition given in Section II. A diffusion processes is one where selection or adoption (rejection) of a behavior or practice depends on an individual decision-making processes that assigns significant influence to the adoption (rejection) behavior of other individuals within the social system. There are a number of ways to define who the 'other individuals' are, and there are also alternative mechanisms through which their social influence may affect an individual's decision-making process. In what follows I briefly identify the social relations that are most significant and three mechanisms which drive the diffusion process.

I start from a simplified version of the decision-making process worked out by Montgomery and Chung (1994) (see also Montgomery and Casterline, 1996) and assume that we are dealing with the adoption (rejection) of behavior B_o and that individuals may choose among a repertoire of 'alternative' behaviors contained in the set $\{B_j\}$ of which B_o is a member. Each of these behaviors is associated with expected costs and expected benefits. Assume that individuals associate each behavior B_j with a distribution of net benefits, NB_j. Let us say for simplicity that NB_j is continuous, can attain values in the interval $(-\infty,+\infty)$, and is associated with probabilities $P_j(x)$, where x is a given level of net benefits. Each individual assigns to behavior B_j a net benefit, $NB_j=x$ with probability $P_j(x)$. This is what we will refer to as linkage between behavior and net benefit. That is to say, for any behavior B_j there is an expected net benefit given by $E(NB_j)=\int_x (NB_j(x))P_j(x)\,dx$. The decision-making problem is simply to choose the behavior within the set $\{B_j\}$ that maximizes E(.).

In the absence of a diffusion process, the inclusion (exclusion) of B_o from the set of alternative behaviors, the actual configuration of the set of equivalent behaviors itself,

and the probabilistic association of net benefits depends on the actors' position in the social system or, rather, on the bundle of resources (including information) associated with or available to the actor. This is what a structural explanation points to: the selection of behavior is solely dependent on characteristics associated with the individual, not with what others do regardless of whom they may be. Instead, a diffusion process exists when either the inclusion of B_o in the set of alternative behaviors, the linkage between behavior and net benefits, or the actual calculus of costs and benefits depends also on conditions dictated by social contacts with other members of the system, however tenuous or formal these may be. That is, these social contacts or social influences are effective mechanisms of diffusion in that they have an effect on (a) information about the feasibility of B_o, (b) knowledge about net benefits associated with B_o, or (c) assessment of net benefits associated with B_o **given a non-zero prevalence of B_o in the social system**.

To make the above definition unequivocal a number of issues require clarification in order**.** **First**, we need precision in the timing of the individual calculus. Thus, we need to know the time horizon for the calculation of net benefits and, more importantly, the time lags required to establish an association between a behavior and its net benefits. If there is no diffusion at all, the time lag may be instantaneous, very short or quite long, but if there is diffusion individuals will surely require some time to learn from other's experience about rewards and costs associated with B_o. And if this is the case, how long does it take for the association to become established from observation of others' behavior?

Second, it was assumed that decision makers are only interested in the mean of the distribution of net benefits, and that issues such as higher risks imposed by higher variances are irrelevant. This assumption may be inadequate both when there is diffusion and in the absence of it, but more so in the first case (Montgomery and Chung, 1994). In fact, when there is diffusion and individuals purposely take into account other's behavior,

it is likely they will have sparse information on rewards and costs of adoption of B_o, particularly at the onset of the process. In such cases, the distribution of net benefits will have higher variances and risk averse individuals will have a harder time adopting the behavior, regardless of what the mean is. This may be one explanation for the phenomenon of resistance to adopt, which is especially relevant at the onset of diffusion process. We elaborate this in (3) below.

Third, to identify the diffusion process from observables one needs to know with precision what are the relevant social networks and the key relations within them. This is the material informed by network theory and is briefly discussed in (2) below. In addition, we should consider two other difficult issues. First, the formation of an individual's reference networks may be endogenous to the process being studied. This means that the selection of networks or of relevant relations within them could be influenced by the same factors that affect decision-making about adoption of a behavior. For example, suppose that individuals in a given social position tend to choose a behavior B_o based on maximization of net benefits purely as a function of their position in the social system, and that there is no influence of other's behavior in their decision-making process. If, to avoid social friction, social rejection or complete isolation, they decide to choose social networks (and relations within them) whose members have also chosen B_o, the **empirical process** will appear as though individual adoption of B_o were associated with prevalence of B_o in relevant networks. The incorrect inference is that there is a diffusion process since the probability of adoption of the behavior will be associated with the relevance of B_o in the individual's network. But in this example membership in a network follows adoption of behavior. The only way to avoid an incorrect inference is to have full information about the timing of the adoption and the timing of effective membership in networks.

The second issue is of great relevance for current processes of diffusion of contraceptive (and other) behaviors that proceed via the influence of television in general

and of the so-called ‘soap operas’ in particular (Potter, 1998). As suggested by Montgomery and Chung (1994), soap operas create fictional networks within which individuals participate. The TV program usually communicates the existence of alternative behaviors (plausibility of contraception, for example) but also transmits information about the connection, usually spurious, between the behavior and observable and desirable rewards. Thus, admired couples in soap operas may have no more than two children, live in mansions, and drive red Ferraris. To the extent that a mansion or a red Ferrari are desirable objects, they will be associated with at most two children. This may introduce, reaffirm or consolidate the idea that children are costly. Thus, although TV is an external source of diffusion, it may operate much in the same way as membership in networks.

Fourth and last, the preconditions for the existence of a diffusion process stated above refer to mechanisms through which social networks affect individual choice of behavior. Montgomery and Chung (1994) suggest that there are two mechanisms: one is by altering knowledge about the elements of the set of plausible behavior and the other is by establishing a linkage between the behavior and its net benefits. There is a third mechanism which changes costs and benefits associated with adoption that are induced by the progression of the diffusion process itself. An example that shows this type of effect is the spread of a technological innovation, such as an operating system. The adoption of the innovation changes the conditions for everybody else, whether they are adopters or not. For example, adoption of an operating system among some users prompts the creation of software designed for the operating system but the software may be useful to the entire collectivity of PC users. The immediate effect should be to increase the likelihood of adopting the operating system simply as a way to access the software. Although examples such as these are easy to identify in the area of technology, they are not altogether absent in the area of social behaviors where we also observe that the social costs of refusal to participate in collective action may grow steeper as members

of a reference group buy into a new behavior. Similarly, the adoption of contraceptive behavior may become more plausible if social and economic conditions emerging after and as a result of the initial adoption of contraception impose steep costs among large families.

This third mechanism acts by speeding the spread of the behavior but is the result of feedback and operates through adjustments that individuals make to changes in costs or benefits, not as direct response to others' adoption. It is a mechanism that augments (inhibits) the diffusion or spread of the behavior by activating the structural factors that affect behaviors. The feedback mechanism operates through the influence of others' adoption on costs and benefits associated with known behaviors, not by altering awareness about a set of options nor by establishing a new connection between behaviors and net benefits. Furthermore, the influence of the feedback effect on an individual's adoption may be exerted by diffuse and distant social networks, not necessarily by any specific social network to which the individual belongs.[7]

In (2) and (3) below I describe in more detail some of the problems we encounter in the definition and treatment of relevant social influences and individual resistance and thresholds. In section VI I discuss considerations for model building.

2. Relational and structural models

The most recent diffusion models that explicitly incorporate the effects of social networks do not neglect the existence of traditional elements altogether. Insistence on the

[7] This third mechanism is associated with a number of interesting formal and substantive problems regarding the possibility of unsftable equilibria and the relation between small changes at the individual level that may translate into large changes at the aggregate level (see Durlauf and Walker (1998). As formulated here this mechanism includes what Arthur identifies as sources of increasing returns that emerge as an adoption process gets underway (Arthur, 1989). Increasing returns can occur due to coordination externalities, advantages associated with learning, and advantages associated with increased information flows. These are all sources of positive feedback. The formulation I suggest here, however, leaves the door open for the possibility that feedback be negative also.

influence of external sources remains an important feature, and the new formulations may even include non-traditional external sources (for example, those that regulate the environment within which decisions are being made). What is novel in these models is a more detailed treatment of the mechanisms through which external sources affect the adoption process. It becomes relevant, for example, to formulate precisely whether a TV show or a particular radio program affects values or preferences, whether it facilitates communication of information among individuals in different social positions, or whether it alters the costs of certain alternatives, etc. The task of model formulation becomes a more taxing one since we must hypothesize in advance the mechanisms through which external sources are thought to affect the adoption process.

The mainstay of these models is attention to the sources of social influence and the attempt to model these as precisely as possible. Classical formal models of diffusion assume spatial and social homogeneity, that is, they rest on the assumption that members of the population do not differ in terms of the chances of affecting others or being affected by others. Sociologists now postulate that there are at least four different mechanisms of interpersonal relations that shape the social structure within which adoption decisions are made. Each of them requires a different modelling strategy. First, **relational linkages** refer to the set of relations an individual may establish with others within a particular setting or network. What matters here is the density of individual connections, as well as the type of connections that some actors in the network have with others outside it. These relations can be represented by an individual, vector valued function. Each individual is characterized by a vector valued function, the contiguity matrix introduced above, that reflects all social connections considered to be relevant. To the extent that relations maintained by others in the network with individuals outside it are relevant for the process, they can be incorporated into the matrix in the form of weights. For example, a set of weights might distinguish the relative importance of strong and weak ties for a given individual in the population (Granovetter, 1973).

Second, **structural linkages** refer to relations with structurally equivalent actors. More generally, they are relations between individuals evaluated as a function of similarity of structural positions occupied within a given network or in the wider social system (Burt, 1987; Marsden, 1998). Application of this idea is fairly common in recent studies of organizational diffusion. Thus, it is thought that structural equivalent relations promote imitation through competition among individuals in a firm. But it can also be the case that competition with structurally equivalent actors may spur not imitation but divergence of behavior (that is, resistance to adoption). This is an empirical matter and can be settled provided we are able to associate with each individual a vector valued function of relations to individuals who are structurally equivalent (or dissimilar). The empirical estimates associated with such a matrix-valued function will enable us to determine the direction and magnitude of effects.

Third, the new models include consideration of influence exerted by **culturally bounded** groups (Strang and Soule, 1997). These refer to relations maintained with individuals based on definitions of actions, status and purpose. For example, the influence of individuals who consider themselves as activists (McAdam and Rucht, 1993) was singled out as an important factor in the spread of activists' tactics. An interesting but somewhat puzzling type of cultural influence might be one generated by the innovation itself. Thus, individuals may align themselves around the notion of being or not being adopters. This could influence continuation of adoption as well as attract (or even repel) non-adopters.

Fourth, and finally, **spatial proximity** can be incorporated into the analysis. A common finding in classic diffusion research is that spatially proximate actors are more likely to influence each other. The difficulty is that spatial proximity is an open concept in the sense that many mechanisms can operate to render it an effective means to promote (or resist) adoption. In most cases, spatial proximity is used as a proxy, albeit imperfect, of network connections and potential social influences originated in either structural,

relational or cultural connections as defined before.[8] Ideally, the use of spatial proximity should be justified *a priori* by defining the precise mechanisms through which it may affect the process. These mechanisms include ease of communication, social and economic homogeneity, frequency of interactions, etc.

For the most part, the study of effects of spatial proximity has been monopolized by geographers (Brown, 1981) but the development of tools for statistical inference from spatial statistics (Cressie, 1991) and the rapid adoption of accessible software (Anselin, 1988) has promoted the diffusion of spatial models of diffusion (see for example Hedstrom, 1994; Bocquet-Appel, 1997).

3. Resistance and thresholds

An important innovation introduced in recent formulations of diffusion models is the notion of individual thresholds. It is postulated that individuals may resist an adoption up to a certain point determined by the external pressure exerted by the prevalence of adoption among others. This is normally measured by the proportion of the population who has adopted or, alternatively, by the proportion of individuals belonging to a relevant network who have adopted. A closely connected notion is that of exposure to adoption which refers to the prevalence of the adoption at any point in time in the population as a whole or in a relevant network (Valente, 1995). While this notion has intuitive appeal, it is a problematic concept to handle and an even more difficult dimension to measure and assess empirically. First, the notion refers to individuals' resistance to adopt and, as such, it must refer to conditions that retard or anticipate adoption, not to the effect or pressure exerted by others. The latter is a conceptually different matter. As a consequence, the notion of threshold is really pointing toward unmeasured conditions that promote (retard) adoption. If all variables affecting the individual decision-making process were known, it would be pointless to speak of

[8]See examples of the application of ideas associated with spatial proximity in the previous discussion of applications to collective action and organizations.

individual thresholds. In fact, it is likely that resistance to adoption and thresholds are related to the variance of the distribution of net benefits associated with the behavior to be adopted (see above). A high variance will prompt risk-averse individuals to delay or reject adoption. In this interpretation, resistance and thresholds depend on (a) perceived variance of net benefits and (b) whether or nor a person is risk averse, neither of which are readily measurable quantities.

Second, the only way to identify the actual existence of thresholds as conceptualized in the recent literature is to assess the effects of the prevalence of the innovation in the system (or in a relevant subgroup) on the risk of individual adoption. But this creates serious estimation (Manski, 1995) and interpretational (Erbring and Young, 1979) issues which have not been carefully addressed.

V. SEARCHING FOR DIFFUSION: THE IDENTIFICATION PROBLEM

1. The ideal test

The only way to conclusively prove whether a diffusion or a structuralist theory is correct is an unrealizable experiment, namely, the observation of patterns of behavior under conditions that hold constant the distribution of individuals by social positions and the distribution of resources associated with positions while allowing variations in conditions that trigger the spread of the behavior (participation in social networks, etc.) If the prevalence of the behavior grows, it cannot possibly be because of structural factors (they are being kept constant) but to diffusion. The key issue, however, is to remember that at least one of the three mechanisms of diffusion identified above mimics the effects of structural changes, namely, when social positions or resources associated with them change **as a result of the process of diffusion itself**. Thus, if we are to identify diffusion effects, the ideal experiment cannot allow the diffusion feedback mechanism to operate and simultaneously maintain invariance in individual characteristics. Thus, even under ideal conditions, it is difficult to sort out precisely how much of the ultimate change in behavior is due to all diffusion mechanism and how much to secondary changes in the

social structure induced by diffusion itself. In the case of the study of fertility or of the bulk of social sciences problems, where conventional study conditions are far from ideal, it will be virtually impossible to make the relevant distinctions. This limitation is of course irrelevant if the feedback mechanism is weak or if it only operates a long time after the process of diffusion is completed.

2. Testable models

The recent literature in diffusion models is very rich in suggested formal representations (Strang, 1991; Strang and Tuma, 1993). I will borrow freely from these but will tailor the discussion to capture useful features for demographic analyses. My purpose is not to suggest what the true models are but rather to provide an indication of the degree of complexity that the models ought to have, and to point to the problems one is likely to face when a diffusion model is misspecified.

A diffusion model must represent individuals choosing among a set of alternative behaviors under a set of constraints. It must also account for the persistence of the adoption or selection over time. This can be done in a number of ways but perhaps the most efficient one is to construct a system of two states, one representing adoption of the target behavior and the other adoption of a different behavior (or refusal to adopt). Individuals may move between these two states as a function of individual characteristics associated with social and economic conditions (costs and utilities), external characteristics acting as constraints (or facilitators), the influence of external sources of ideas, and the influence of individual's social networks. To capture the dynamic of this two-state system we can formulate a pair of equations for the risk or hazard of transitions between the two states:

$$\mu_{12i}(t)=\mu_{o12}(t)\exp(\ \mathbf{X_i}(t)+\ \mathbf{Z_i}(t)+\alpha\mathbf{W_i(t)G(Y(t))}+\ _{i12})$$

$$\mu_{21i}(t)=\mu_{o21}(t)\exp(\ \mathbf{*X*_I}(t)+\ \mathbf{Z*_I}(t)+\alpha\mathbf{W*_I(t)G*(Y*(t))}+\ *_{i21}) \qquad (6)$$

where $\mu_{12i}(t)$ refers to the risk of moving from state 1 (non adopter) to state 2 (adopter) for individual I at time t, $\mu_{o12}(t)$ is a baseline hazard, $\mathbf{X_i}$ is a vector of 'structural characteristics' of individual I, $\mathbf{Z_i}$ is a vector valued function containing information on external sources of information that may influence ith's choice, $\mathbf{W_i}$ is a contiguity vector for individual I containing the weight assigned to the influence from contacts with individuals j=1,..., N, where is N is the total number of members in the system, **G** is a functional transform and **Y** is a vector of responses for members j=1,..., N. Finally, $_{12i}$ is an error term. The second equation defines the risk of moving from state 2 to state 1 (abandoning the new behavior). It is analogous to the first but I have allowed for the possibility of different baselines, different effects and different matrices of covariates. The contiguity vector is time dependent to allow for changing influences derived from social networks during the process and so are the vectors of responses **Y** and **Y*** to allow for updating of information about members of the system.

a) Problems in the formulation of the model

Before reviewing estimation problems, let us examine the anatomy and functionality of this formulation. Suppose that this two-state model is correct. Under fairly general regularity conditions, there will be a steady state and a stable proportion of the population which will be in each of the two states. It is not difficult to show that those proportions or their logarithms are NOT a simple linear function of the vector of covariates, as the logarithms of the risks are. This statement is important: it means that if model (6) is the true representation of the diffusion process, aggregate linear models for quantities such as the proportion of adopters are misspecified. In addition, since the model is misspecified, it is totally meaningless to estimate its parameters and to attribute to diffusion the part of the variance in the dependent variables (proportion of adopters) that remains unexplained by measured covariates.

Furthermore, let us say that variables are scaled in such a way that α and are

positive. It follows that if diffusion is effective, the adoption process will proceed faster than it would do otherwise (the risk of adoption will be higher and the probability of staying in state 1 will be lower). But this does not mean that one is correct in inferring the existence of diffusion if the change in the aggregate proportion of adopters is "rapid" or "fast" (relative to some standard). This is because (a) we assume that the second transition is nonexistent and (b)we assume that all relevant structural covariates are contained in **X**. Even if the second transition was irrelevant (all adopters remain adopters for life and beyond), lack of appropriate control for structural conditions that change rapidly and that have strong effects on the risk of adoption will end up concealing the degree to which the process is structurally driven and mislead the investigator into believing that the whole process is the work of diffusion. Note that this will occur even if one is estimating model (6) rather than an aggregate variant of it and irrespective of whether the X's are unrelated to the Z's.

There are a number of difficulties associated with and possible extensions of model (6). First, we have not justified well the nature of the term associated with social networks. In particular, there is no reason why it should include all members of an individual network. An alternative representation would be to split the term into two components in the following way:

$$\alpha \mathbf{W_i(t)G(Y(t))} = \alpha_1 \mathbf{W_{1i}(t)G_1(Y_1(t))} + \alpha_2 \mathbf{W_{2i}(t)G_2(Y_2(t))}$$

where each vector now refers to individuals in the network relevant for the ith individual according to their response, and collects all those who have not adopted in W_{1i} and all those that adopted in W_{2i}. This partition will enable us to distinguish what are the effects of attraction toward the new behavior (exerted by those who adopted the behavior) from the potential resistance effects exerted by those who have not yet adopted.

A second problem is whether the model must be multiplicative at all, that is, one

where the diffusion component and the structural component enter as multiplicative terms. Strang and Tuma suggest pursuing an additive model that has some desirable properties (Strang and Tuma, 1993). Since estimates and implications will be different, the researcher must think through the assumptions made when adopting one or the other form.

Third, effects of diffusion operating through external sources should be captured by whereas effects of social influence will be captured by α. Both and α can be allowed to be vector-valued, that is, individuals may have different 'susceptibility' to others' influence depending on who the other individual is. If one considers this an important extension, then problems of identification will emerge. Whether α and are scalar quantities or vector valued functions, their magnitude and sign will only reflect two mechanisms of diffusion, one whereby social influences change the set of plausible choices for the individual, and the other whereby social influences modify the linkage between the new behavior and expected net benefits. These effects **will not** capture the influence of the diffusion process via the feedback mechanism. In order to capture the feedback mechanism, model (6) must be extended to reveal the relation between prevalence of the new behavior and structural conditions contained in $\mathbf{X}_{i.}$ Alternatively, if the feedback mechanism requires too long a time to operate relative to the speed of diffusion to be significant, one could simply dismiss it.

Fourth, there is no need to have a unique contiguity vector, $\mathbf{W}_i$. In fact, one could partition the vector to reflect several (partially related) networks or to attempt to represent functional and structural influences (see discussion above). Furthermore, one could introduce a vector representing the 'success' associated with the adoption of the behaviors by members of relevant networks (see above). These two modifications increase the richness of the social network representation but they also pose additional data demands.

b) Problems of estimation

If we insist on the existence of two transitions, the first problem that emerges is that of the relation between the two error terms. Without assuming a joint distribution for the errors (and, inevitably, this will be arbitrary) the parameters are not estimable. Of course, the easiest but least appropriate solution is always on hand, namely, to assume that the two error terms are independent.

But even a simplified, one-equation form of model (6) creates estimation problems of considerable import. Assume the simplified form that results when the transition from state 2 to state 1 (abandoning adoption) is insignificant. That is, we assume that once adoption occurs, it is irreversible. This is consistent with the process of fertility decline in general, although it may not be with other diffusion processes or with some examples of local fertility decline. Also, to simplify even further, assume that there is no relevant feedback mechanism. The parameters of the simplified model that remain will be estimable only if we have available considerable amounts of information, and if we make some strong assumptions along the way.

The information required includes (a) the nature of several types of networks relevant to all individuals in the population during the trajectory of the process, (b) information on outcomes associated with adoption of the new behaviors by members of the networks in which all individuals participate, (c) the nature of the sources of external influence to which each individual is susceptible throughout the duration of the process and, finally, (d) relevant structural conditions that determine either individual positions or external constraints that must be taken into account in individual decision-making. Needless to say, there are very few data sets in sociology or demography that contain all this information, and even fewer social scientists who will be able to discern what all the relevant variables are. As a result the researcher faces the problem of unmeasured heterogeneity whereby estimated effects are inconsistent even if the omitted variables are unrelated to the included variables. It is not difficult to design scenarios where omission

of a structural characteristic could impart an upward bias on α (or) misleading the researcher into believing that there is a non-trivial diffusion process. Note that, unlike most cases where generalized linear models apply, the biases or inconsistencies will occur irrespective of whether or not the omitted variable is related to those included in the model. In section V we identified one potential culprit of unmeasured heterogeneity, namely, information on the appraisal of the risk to which an individual is exposed when connecting the new behavior to net benefits. If some individuals perceive a larger variance than others and they are risk averse they are likely to delay adoption. This will lead to a well-known artifact: the risk of adoption will look like a decreasing function of time. The most likely consequence of this will be to bias downward the effects of diffusion.

Unmeasured heterogeneity can be modelled and one of the most effective ways of doing so is to postulate that each individual is characterized by a resistance (or susceptibility) to innovation or a 'threshold' for innovation. This unmeasured individual characteristic is postulated to be a random variable with a known distribution. The assumption just made leads to calculations that result in a marginal risk which is not dependent on the unmeasured characteristic. Thus, the formulations of diffusion process or collective actions that invoke the existence of individual resistance or individual thresholds are really designed to interpret the existence of unmeasured characteristics that either promote or delay the adoption of the behavior. And the hazard model formulation offers a framework in which to include them.

Finally, a more troublesome feature of a diffusion processes is that its own progress may affect the likelihood of reducing, eliminating or inventing new social networks. Maintaining social networks that are not responsive to the new behavior may force adventurous individuals to seek new social attachments among those better prepared to embrace the new behavior. Although this avoids friction and possible penalties it is associated with new costs and individuals will need to weight the advantages of leaving

current social networks perceived to be unfavorable with the cost of creating new relations in newer and more receptive networks. Ultimately, however, what matters is that such endogenous change will produce the appearance that networks do have an influence on choice of behavior when they may have none. Naturally, the only way to handle this problem is to model separately network formation as a function of past behavior. This imposes more information constraints and generates new estimation difficulties.[9]

VI. DIFFUSION MODELS IN DEMOGRAPHY

In this last section of the paper, I review the history of application of diffusion models in demography and contrast each stage in this history with the requirements spelled out before. More recent models are closer to what we would like them to be but suffer from inaccessibility to adequate data. More traditional models are insufficient and inadequate. I start with a review of how the problem has been viewed and approached, and then describe three stages in the history of the application of diffusion models in demography. Most of the issues discussed in this section pertain to fertility but in section (3) below I discuss a handful of problems related to theories of mortality theories.

1. Explanation based on diffusion and on structural factors

In sociology, as in demography, the opposition between diffusion processes and structural processes is posed explicitly as a theoretical problem. But the practice has been to relegate diffusion to the corner of what cannot be explained with indicators and measures of structural factors. As a consequence the exact mechanism through which diffusion operates is either not identified at all or is poorly described. For example, the internal colonialism theory developed by Hechter (1975) is based on an assessment of the explanatory power that indicators of industrialization (structural factors) have regarding voting behavior patterns. What could not be explained by measured factors was

[9] For a review of the processes of network formation see Doreian and Stokman (1997)

associated with a peculiarly traditional behavior spread and reinforced by membership in a fringe. Exceptionally, Hechter goes to great length to explain what the 'residual' mechanism is. In demographic analysis, a similar line of thought prevails in the explanation of fertility and mortality decline: we gather evidence about social and economic conditions and changes in demographic outcomes, and then use the former to explain the latter. What is not explained--frequently the bulk of the outcome--is interpreted as the result of diffusion or something that is not entirely equivalent to diffusion but is frequently confused with it, cultural factors. In most cases, the authors leave in the dark what these residual mechanisms are. Perhaps because of this tradition we tend to think of diffusion as a process that does not involve individuals making decisions, processing information to calculate risks, or evaluating costs and returns. Instead we conceive of it as a rather obscure set of actions, with no apparent rational basis, and inconsistent with observed social and economic conditions of one sort or another.

In order to gauge the shortcomings of conventional approaches to the study of fertility, and the progressive elimination of some of them, I will evaluate them against the standard defined before. In this section of the paper I suggest conditions required for an explanation based on a diffusion process to hold: what exactly is it that we should find in the empirical evidence to reveal that a diffusion process is at work? How are we to distinguish processes that operate primarily through diffusion of a behavior from those where behavioral changes occur as a result of other changes in the social system? How can we distinguish whether a protest movement emerged, developed and died out as a result of a genuine process of adoption of protest as a new behavior rather than as a result of external stimuli or the degree of organization of participants? How can we tell if adoption of contraception is an outcome of a process of spread of an innovation rather than the result of changes in socioeconomic conditions?

Although there might be conditions that are model-specific, there are some general

requirements for the identification of diffusion. One important condition is that the individual probability of adoption at time t should be a positive function of the established social networks of an individual among those who have (and have not) adopted. The effect may be mediated by social or geographic distance or by other structural characteristics, but it ought to be revealed as a distinct influence, different from and in addition to those associated with changes in structural conditions.

Section VI also makes it clear that to identify a diffusion process we need to represent it as an individual decision-making process where preferences and opportunities figure as prominently as they do in other processes. From the model introduced in section V, we concluded that studies of the aggregate proportion of adopters is likely to lead to model misspecification. Similarly, information on the rate of adoption (as reflected, for example, in changes in fertility rates) indicating that a process is proceeding too fast or too slow (relative to some expected rate), cannot be taken as *prima facie* evidence of diffusion. Unless the magnitude and sign of the deviations between observed and expected change is at least correlated with measured factors associated with diffusion, this regularity cannot be taken as more than very weak evidence for a diffusion process.

2. Searching for evidence of diffusion in demographic processes.

The demographic literature on mechanisms of fertility decline is quite complex and contains arguments which are seemingly contradictory with each other. If a sociologist of knowledge, however, surveyed this work she would find that there are about three intellectual stages than bring us to the present. In each stage there is an opposition between two types of explanations for fertility decline, and with the passage of time such opposition has been tinkered with and reformulated as new evidence and new paradigms became new parts of the controversy.

a) First stage: Forging a risky dichotomy that stayed with us, the 'structuralist' versus 'diffusionist' explanations

In the aftermath of the Princeton Fertility study, the debate about mechanisms of fertility decline has polarized. On the one hand stand those who argue that fertility decline requires what we have referred to as 'structural' transformations, of the sort contained in imageries of industrialization (involving many dimensions such as overhaul of the division of labor, commodification of labor, integration of regions through a market economy, and massive monetization), state centralization with monopoly of activities traditionally relegated to the family, and emergence of impersonal bureaucracies. On the other stand those who argue that fertility decline is more likely to proceed via a diffusion process, where either ideas and preferences about family size and family limitation or knowledge about the means to achieve it are passed on from social group to social group and, within groups, from member to member (Coale and Watkins, 1986).

This dichotomy was formulated in a testable way in the demographic literature well before most results from the Princeton study were available. Indeed, the empirical analysis of the data to sort out between the two explanations emerges explicitly for the first time in a seminal paper by Carlsson (1966). In it the author used an even more unfortunate contra position, namely, between processes of adjustment rather than structural transformations and diffusion. Carlsson argued that fertility decline in Sweden could have been triggered by either an adjustment process, whereby families adjusted their fertility targets to accommodate to higher levels of child survival, or it could have been the result of a diffusion process whereby a few forerunners introduce controlled fertility and are then imitated by others who adopt the innovation. Carlsson inferred the 'adjustment' hypotheses from a classic formulation of demographic transition theory that assigns a fair amount of importance to mortality decline as a precursor to fertility decline (Davis, 1963; Notestein, 1945).

Carlsson's dichotomy is unfortunate for two reasons. The first is that his

'adjustment' hypothesis is indeed one possible version of a structuralist argument, and in presenting it as a sharply different, competing explanation to a diffusion argument, he falls into a trap that has confused us for years. The confusion is that, as explained before, we think of diffusion as a process that involves irrational or a-rational individuals whereas the structurally-based explanation invokes rational decision makers. I have suggested that this interpretation is incorrect, and that the difference between one and the other has nothing to do with the lack of actors' rationality in one case and its presence in the other case, and everything to do with the possibility of a distinct rationality, one where others' opinions either do or do not exert influences on actors' fertility calculus. Later I will argue that the contraposition of rational adjustment and a-rational change due to diffusion is as mistaken as the contrast between changes driven by ideational as opposed to structural factors.

The second reason why the dichotomy as formulated by Carlsson is misleading is that the main mechanism through which the process of adjustment was supposed to work involved improvements in child survival. If there is anything we learned from evidence gathered in Western Europe or in developing countries, it is that, in most regions of the world, mortality decline has little to do with fertility decline, and that none of the three mediating mechanisms linking mortality and fertility--biological, replacement and hoarding--are powerful enough to carry the explanatory day (van de Walle, 1986; Preston, 1978; Cohen and Montgomery, 1997; Palloni and Rafalimanana, 1997). Few amongst us would argue that the failure of this particular (Carlsson's) version of the structuralist argument is reason enough to sponsor the diffusion hypothesis.

The testing procedure used by Gosta-Carlsson is of some interest. The author utilizes regional fertility data in Sweden to, among other things, assess the hypothesis that fertility decline was due to a diffusion-like process. He begins by working with the proportion of individuals practicing contraception by region. This proportion is estimated assuming a fixed level of natural fertility and a fixed level of fertility associated with

contraception. The author then assumes that this estimated proportion of contraceptors can be modelled as a very simple logistic process where there is only one external source of diffusion. Using an assumption about levels of fertility among contraceptors and non contraceptors, the author translates the model for proportions practicing contraception into a model for fertility rates, or more precisely, for changes in fertility rates. The end result is a simple autoregressive model for fertility rates. After fitting this model with a simple linear regression function he concludes that it does not fit well as small regions seem to be peculiarly unexplained outliers. A further refinement to the model including a test of regional interactions fails to significantly improve the fit. In the end, Carlsson fits another model that includes lagged values of infant mortality and is able to account better for regional variability in fertility. In the author's view this supports his conclusion that fertility decline was driven by an adjustment not a diffusion process.

Although Carlsson's effort is the first formal representation and testing of a diffusion model, the application is fraught with problems. The most important among these is that there is no model for the decision-making process that includes social influences. Although the author does consider this (in the form of geographic proximity) social influences are not originally formulated in his logistic model and are introduced as *ad-hoc* variables. It is interesting to note that Carlsson's theory falls in the trap of reducing a diffusion model to a simple movement of information from an external source to other members. Indeed, in his view his test was an effort toward producing a shift from "...innovation to adjustment theory [which] leads to less emphasis on information about birth control and its means, and more emphasis on motivation and social situation...." (p. 173). As we have seen before, this characterization of a diffusion process is faulty. However, he recognizes the problem generated by the possibility of individuals rejecting the new behavior after adoption and concludes that "...One reason why it may be more misleading than helpful to regard the fertility decline and the wider adoption of birth control as an innovation process is that the latter designation often

carries with it the idea that the process is bound to run its course to complete or near-complete adoption in a regular way. The notion of an adjustment over time to a new equilibrium level, on the other hand, keeps open the possibility of fertility staying neither fully controlled in the modern sense, nor completely uncontrolled , and this for an appreciable period" (p. 172). This extensive quote suggests that despite identifying the problem of rejection identified before, Carlsson could not conceive of a solution within the diffusion model, as we did in Section VI using a two-state hazard model.

b) Second stage: the Princeton project and its aftermath

The results of the Princeton project not only cast doubts on the validity of classical explanations of fertility changes, but they also encouraged formulations of more nuanced interpretations of the 'diffusionist' models. By far the most damaging empirical evidence produced by the Princeton project against a paradigmatic version of the structural explanation, conventional demographic transition theory, is that fertility decline appears to occur along territorial boundaries reproducing ethnic, language and religious boundaries (Lesthaeghe, 1977; Livi-Bacci, 1971, 1986; Knodel, 1974; Coale and Watkins, 1986). Conventional regression analyses reveal that the explanatory power of variables measuring industrialization, urbanization, state centralization, bureaucratization and others to predict the onset and the pace of fertility decline turns out to be at best modest.

It would be a mistake to believe that the studies that are part of the Princeton fertility project are identical or even very similar. Though following a unique blueprint for the measurement of basic indicators, each of them utilizes different statistical procedures and strategies to verify hypotheses. However, with the exception of the work by Lesthaeghe on Belgium's fertility decline (Lesthaeghe, 1977), the contrast between the structuralist and diffusion theories is always resolved by estimating fairly conventional linear regression models on aggregate indicators of fertility, and using residual analyses as a tool to assess the degree of failure of the structuralist theory or, conversely, the

degree of success of the diffusion model.

The question of whether different data and/or different models would have led the researchers of the Princeton project to different conclusions is, of course, pertinent. However, more recent analyses do not seem to point in one direction more than another. Thus, armed with more sophisticated analyses and more detailed data on structural factors, researchers have been able to allocate far more importance to structural conditions than to diffusion in some parts of Europe (see Galloway et al., 1994). In contrast, the application of modern tools for spatial analysis to directly test the idea of diffusion reveals that, at least in England and Wales, the fertility decline is likely to have been driven by a diffusion process (Bocquet-Appel, 1997).

In addition to these two very recent tests of the diffusion hypotheses, there are some efforts under way to convert the fertility measures used in the Fertility project (If, Im, Ig) into more meaningful indicators of prevalence of contraceptive behavior. It should be remembered that Carlsson was the first to propose a technique for doing so, albeit a crude one. In a series of papers Okun and colleagues (Okun, 1994) have suggested ways of estimating the proportion of contraceptors, quantities that are closer to diffusion models of fertility behavior. Assuming that results from this work were to produce accurate estimates of the desired quantities, how could one falsify a diffusion hypothesis? How could we identify a diffusion process from among alternative ones?

Some desirable conditions for identification with the data described above are the following:

a) One needs to verify that the measure of prevalence of the behavior at one time is 'responsive' to levels of that behavior in the recent past. Or, equivalently, in a time series of the outcome or behavior we should expect to observe a high degree of positive autocorrelation. This is a condition sought, for example, in the model posed by Carlsson (1966) and those more recently studied by Montgomery and Casterline (1993). Although this is widely thought to be a distinctive marker of a diffusion process, it is not altogether

clear how crucial it may be. In most processes of diffusion it may well be that the association between current and past levels of adoption will change according to the stage of the diffusion process. For this condition to be essential, it must be derived from the formulation of the diffusion model at the individual level. For instance, if the individual probability of adoption of contraception is expected to increase when other members of a given network also adopt, does this always result in an aggregate level positive autocorrelation of the response?

b) there should be an interaction between the prevalence of the behavior and conditions that promote social influence and communication or those that delay adoption. Indeed, prevalence of the behavior should increase more rapidly in groups that are more homogeneous and more slowly in groups that are heterogeneous. In the particular case of Western Europe, we would expect the estimates of prevalence of behavior to change more rapidly within subregions that are ethnically, linguistically or culturally homogeneous. Here again, there may be conditions under which this desired condition is not met even though a diffusion process could still be the explanation of the process. Thus, for example, it is in homogeneous groups where sanctions are more likely to be applied efficiently against individuals who depart from conventional norms. Under these conditions, it would be individuals in heterogeneous social settings that would be more able to change their behaviors.

c) there should be a strong interaction effect between past levels of the behavior and the strength of influence of external sources.

d) All three of the previously mentioned effects should disappear if one assesses directly the effects of social interactions or social influences that are posited to operate as conduits to spread the behavior.

Despite the fact that the procedures through which diffusion has been inferred in the Princeton fertility project do not meet these strict conditions for proper testing of diffusion models, it is difficult to escape the ‘gut’ feeling of a European landscape of

fertility decline drawn along lines that do not coincide with those traced by the forces of industrialization, urbanization, and the like. Ethnicity, religion or language are identifiers of normative or evaluative standards that appear to either retard or accelerate fertility changes. To predict the onset of fertility decline in a region or territory, the pace of changes and even the ultimate levels, it is often more relevant to know the nature of these identifiers than to assess the levels of development, industrialization, or urbanization. Much the same appears to be true in countries now undergoing the fertility transition.

At the end of the nineties demographers had already surveyed extensive territories in addition to Western and Eastern Europe. The World Fertility Survey, the Demographic and Health Survey and a handful of other more localized data collection undertakings, had produced a large amount of evidence regarding fertility decline in developing nations. In a sweeping and controversial summary of this evidence, Cleland and Wilson (1987) suggest that any version of demand theories of fertility, that is, economic theories invoking the need of structural changes in individuals' positions as a precondition for fertility changes, cannot account for the onset, pace and geographic location of fertility declines throughout the developing world. Instead, these changes appear to be driven by 'ideational' changes riding on the back of a diffusion process. Much the same conclusion had been reached by Caldwell in some of his writings where he assigns importance to the onslaught of an ideational change ("westernization") that precedes and is independent of changes in the forms of production and distribution (Caldwell, 1982). The evidence that Cleland and Wilson use to support their arguments belongs to a type identified before: they examine the speed of changes in fertility and compare them with what would be expected given observed changes in structural conditions or, alternatively, they verify that the main cleavages created by fertility changes are drawn by ethnic or language distinctions.

More recently, Bongaarts and Watkins (Bongaarts and Watkins, 1996) review empirical evidence regarding the timing and pace of recent fertility declines. As Cleland

and Wilson do, they too reach the conclusion that much of what we observe during the past twenty or thirty years is attributable to the transmission of information and ideas regarding fertility control. Their conceptualization of what is being transmitted and how it is transmitted is broader and perhaps more precise than Cleland and Wilson's and includes both micro level diffusion processes (at the level of local networks and peers) as well as macro level diffusion (global and national 'networks'). But although their analysis is more systematic than Cleland and Wilson's, it is mainly based on linear shifts analysis which rests on the unverified assumption that the magnitude of unexplained accounted for by shifts is associated with mechanisms facilitating diffusion. This may be suggestive but it is certainly not rigorous proof.

Although, as was the case with the conclusion of the Princeton project, it is difficult to disagree with Cleland and Wilson's (or with Bongaarts and Watkins's or Caldwell's) ultimate conclusion, it is another matter altogether to infer that they followed the proper procedure to infer it. Quite apart from the fact that the manipulation of evidence remains unsatisfactory as a test of the diffusion hypotheses, Cleland and Wilson and to some extent Caldwell (but not Bongaarts and Watkins), introduce a confusion that seems to make equivalent ideational changes with diffusion processes. If fertility declines because individuals change ideas about the advantages of having children even though their social and economic positions remain apparently the same, one cannot infer the existence of a diffusion process. If, on the other hand, there is evidence that the new ideas or the change of ideas are driven by imitation of others' ideas, then we can conclude that there is at least some type of diffusion at work.

The best way to understand this distinction is to utilize Coale's formulation, 'ready, willing and able' or (RWA). For fertility decline to be possible three conditions must be satisfied. First, fertility control must be within the field of conscious choice or, equivalently, the new behavior, B_o, must be a member of the set of feasible behaviors among which the individual can choose. A necessary condition for this to happen is that

there should be information flowing from members of an individual's network or by external sources of information. The idea of a new behavior must appear from somewhere. But this alone is not always sufficient. In some cases structural changes will be needed to enable individuals to include the new behavior in the repertoire of possible behaviors. From this point of view, some diffusion must always exist. The question is whether it is sufficient to make individuals 'ready'. When we refer to 'ideational' change we seem to have in mind at least this dimension of the process. But if so, ideational change and diffusion should not be used as equivalent concepts since ideational changes may depend on structural changes also.

The second and third condition can be considered simultaneously since they are two parts of a model of rational decision-making. Individuals must be willing to engage in the new behavior and they must be able to do so. Being willing refers to the ability to detect net benefits associated with the new behavior--what we referred to in section V as the linkage between net benefits and behavior. Being able simply refers to the accessibility to means to engage in the behavior and to the ability to bypass institutional constraints that impede the practice of the behavior. As we discussed before, a diffusion process can affect both the ability to establish a linkage between the behavior and net benefits and to erode social resistance to the new behavior.

What is important to note here is that Coale's preconditions involve both ideational changes as well as non-ideational changes but that all three preconditions could be affected by diffusion processes. This should make it clear that if fertility is attributable to an ideational change it does not follow that it is produced by diffusion or vice versa.

In very recent work, Lesthaeghe attempts to empirically assess the state of these three conditions in the context of some developing countries, and to determine their influence on the onset and speed of observed fertility changes (Lesthaeghe and Vanderhoeft, 1998). In order to test diffusion models, however, one would have to

estimate the effects of social influences (and feedbacks) on the level and patterns of each of the three components. It would then be straightforward to calculate the contribution of diffusion to observed fertility changes, and to estimate the relative weight of the influence of the diffusion mechanisms across the conditions contained in the RWA set.

c) Third stage: recent advances

Recent developments in model formulation and empirical analyses have improved upon previous applications. There are three types of improvements. The **first** type consists of formulating explicitly an individual-based decision-making process, introducing the operation of individual influences, and then creating a model-representation of the process whose parameters are estimable from available data. Once parameters are estimated, hypotheses testing is carried out to determine if the value and sign of estimates are what we would expect if social influences were intrinsic to the decision-making process.

The bulk of this work has been carried out by a few researchers but mainly by Casterline, Montgomery and Rosero-Bixby in various publications (Rosero-Bixby, 1991; Casterline, Montgomery and Clark, 1987; Rosero-Bixby and Casterline, 1993; Montgomery and Casterline, 1993, 1996; Montgomery and Chung, 1994). Their work has focused on two types of models. The first are those derived from compartment models that lead to a representation of aggregate fertility rates over time and across many geographic units as an autocorrelated process (Rosero-Bixby, 1991; Rosero-Bixby and Casterline, 1993). The second type of model starts from a similar decision-making process but introduces explicitly the operation of social networks, albeit in simplified form. These models are analogous to those proposed by Erbring and Young (1979) and Marsden and Friedkin (1993) and are limited by similar estimation problems (Montgomery and Chung, 1994; Montgomery and Casterline, 1996). This second type of model is more data demanding since one needs information on social networks and these are rarely available to us. Whether one uses one type of model or the other, and whether

the data come from Costa Rica (Rosero-Bixby and Casterline, 1993) or from Korea (Montgomery and Chung, 1994), the results always suggest the importance of diffusion processes.

The model that explicitly includes social influences is very general and has the advantage that it enables us to translate seemingly dissimilar processes into a common framework. For example, Futing Liao (Futing Liao, 1994) proposes to study family planning programs as example of collective action, complete with reference to collective goods, free rider problems, issues of organization, etc. If this turns out to be a parsimonious representation of the process, it can be easily accommodated through formalization similar to the ones used by Montgomery and Chung or even by those utilized in the study of social protests (Myers, 1997). This is because, as discussed before, what is crucial for a collective action model formulation is identical to what is crucial for the diffusion model, namely, the definition of social influences.

One of the shortcomings of this type of model is that it does not specify the network dynamics in detail although it allows simplified representation of what social influences are. In a **second** line of improvements researchers focus much more rigorously on the actual configuration of networks in which adopters and non-adopters may participate. In particular, the models are formulated to understand the dynamic interplay between individual decision-making and the aggregate properties of the system, notably the continuous reshuffling of network connections that take place as the diffusion process advances (Kohler, 1998; Durlauf and Walker, 1998)

The **third** line of improvements is first suggested by Bocquet-Appel (1997) and consists of applying spatial analysis to a transformation of Coale's fertility indices calculated for England and Wales. The procedure consists of two stages. The first is data smoothing which leads from association of indicators to small (and nonexistent) geographic units; the second tests for the existence of a form of contagion process; the third represents graphically the progression of the process using the parameters estimated

by the model. Bocquet-Appel's study reveals the importance of contagion in the process of fertility decline in England and Wales. Yet, because this is an approach that relies solely on spatial proximity, we are left in the dark about the actual social mechanisms that may have been operating.

3. The study of mortality and diffusion models

Although attention to diffusion models in mortality and health has been far less intense than that devoted to fertility, it is not less true that in this area there is also a controversy that pits a diffusion model against a structural model.

The most important controversy about mortality decline has been about the factors responsible for increases in life expectancy during the period after 1850 in Europe and after 1945 in developing countries, particularly in Latin America and Asia. One side of the controversy argues that the bulk of changes should be attributable to changes in 'structural' conditions affecting the levels of well-being of the population (McKeown, 1976; Fredericksen, 1966; Arriaga and Davis, 1969). The other side assigns more importance to a process of diffusion whereby both knowledge about and techniques to prevent and cure diseases are transferred from one social group to another. The diffusion can be from a central source, as occurs for example when a central government, under the influence of international organizations, organizes a campaign of vector eradication, or when these central governments become importers and users of chemotherapeutic techniques. Alternatively, diffusion can be driven by internal sources, as when individuals in selected social groups learn about the origins, prevention and cure of illnesses. Preston and Haines (1991) and Preston (1978) have argued convincingly that germ theory and its worldwide diffusion has a very strong effect at least on the initial phases of mortality decline.

Coale's RWA framework could be useful in the study of mortality and morbidity as well. To the extent that exposure, susceptibility and cure of some illnesses depend on behaviors that may or may not be within the repertoire of feasible behaviors, there is a

need to understand how is it that they are finally incorporated. And, as in the case of fertility, diffusion will be in part responsible for including such behavior into a feasible repertoire. That individuals carry out cost-benefit calculations before adopting a behavior that may reduce exposure to an illness, decrease susceptibility or augment resistance, is not farfetched: there are plenty of examples where groups do not adopt a practice that is clearly beneficial for their health. As in the case of fertility, a diffusion process may be responsible for generating a linkage between a behavior and its net benefits. In this sense being willing to improve health is as much a dilemma as is being willing to adopt contraception. Finally, historical studies provide strong evidence suggesting that institutional constraints may get in the way of adopting measures that could reduce exposure to illnesses. Thus, for example, the fascinating account by Evans of the last cholera epidemic in Hamburg (Evans, 1991) reveals that although the R and W elements in Coale's paradigm were favorably set, class conflicts and political clashes occurring at a macro level, were disruptive enough to impede the speedy and efficient adoption of measures to prevent the spread of the epidemic: the A switch in the paradigm was not properly set. In this case, diffusion of the ideas of germ theory did not translate into collective benefits because of structural constraints.

The above discussion makes it clear that testing diffusion models pertinent for mortality and morbidity is no less useful than in the case of fertility. Moreover, the formal representation of the processes of diffusion need not depart from the one used in fertility. And yet, all the model building that has taken place up to now is subjected to the weaknesses revealed for the case of fertility. In particular, the empirical analyses infer the existence of diffusion (or something other than structural changes) as the source of mortality decline from regression estimation and the corresponding examination of residuals that follows (Preston, 1980; Palloni and Wyrick, 1981). It is only in a handful of studies of aggregate data (Preston and van de Walle, 1978; Palloni and Wyrick, 1981) that the corollaries of a diffusion model are tested. By the same token, studies testing

models that regard the success of health interventions as a function of its properties as collective action are rare, and have not linked well the ideas of collective action theory to those of diffusion processes. For the most part, the application of ideas about diffusion processes to the area of mortality and morbidity has been relegated to a small corner of the field and made the object of study of medical anthropologists working on disconnected case studies.

VII. SUMMARY AND CONCLUSIONS

The main task of this paper was to derive the conditions for testing the existence of diffusion processes and some of its mechanisms or, equivalently, to formulate the conditions of empirical identification of diffusion processes. I begin by recognizing the opposition between structural and diffusion-based explanations and confirmed that this contrast is pervasive in demography and sociology and that, in most cases, it is ill-posed, ill-defined, and poorly resolved through empirical analyses. In particular, I suggest that the opposition tends to undermine and neglect the decision-making process that is at the root of every diffusion process.

Using previous discussions on the subject, I introduce a preliminary definition of diffusion which enables me to identify key elements of a diffusion process. These were decision-making, resistance and thresholds, social influence, rejection and feedbacks. Armed with the preliminary definition I undertake the task of reviewing broad areas of application of diffusion models in sociology and demography in general, identify several stages in the history of applications, and settle down for recent applications in collective action and organizational theory as examples of what would be near-to-ideal conditions for model formulation and testing of diffusion processes. This review leads me to
a) the elaboration of a refined definition of diffusion, one which highlights what was unique to a diffusion process, namely, the significant effects of social influence, and three mechanisms through which the effects of social influence worked;
b) the construction of a golden standard or model that represents and distinguishes

between the mechanisms of diffusion; and

c) fairly precise conditions for empirical identification of such processes.

A review of research in the area of fertility reveals that only very recent applications and hypothesis verification meet the stricter standard. Previous applications are far too removed from the golden standard to be taken as anything more than useful suggestions. Applications of diffusion in the area of mortality and morbidity are rarer but equally limiting. I suggest that it is conceivable that frameworks similar to those used in fertility, particularly Coale's RWA and applications such as those elaborated by Lesthaeghe, could be quite useful in this area. If so, modelling mortality and morbidity processes with the help of a diffusion-based formulation should prove to be feasible and attractive and will cease to be the province of a handful of seemingly esoteric applications.

References

Aldrich, Howard E. 1979. *Organizations and Environments*. Englewood Cliffs, NJ: Prentice-Hall.

Anderson, R. M. and R. M. May. 1992. *Infectious Diseases of Humans*. Oxford: Oxford University Press.

Anselin, Luc. 1988. *Spatial Econometrics: Methods and Models*. Boston: Kluwer.

Arriaga, E. D. and K. Davis. 1969. "The Pattern of Mortality Change in Latin America." *Demography* 6(223-42).

Arthur, Brian, W. 1989. "Competing Technologies, Increasing Returns, and Lock-in by Historical Events." *Economics Journal* 99:116-31.

Bailey, N. T. J. 1975. *The Mathematical Theory of Infectious Diseases and Its Applications*. London: Charles Griffen.

Bandura, Albert. 1986. *Social Foundations of Thought and Action*. Prentice-Hall.

Bartholomew, D. J. 1982. *Stochastic Models for Social Processes*. New York: Wiley.

Bocquet-Appel, Jean-Pierre. 1997. "Diffusion Spatiale de la Contraception en Grande-Bretagne, a l'Origine de la Transition." INED. Seminaire Demodynamiques. July.

Bongaarts, John and Susan Cotts Watkins. 1996. "Social Interactions and Contemporary Fertility Transitions." *Population and Development Review* 22(4):639-82.

Brown, Lawrence. 1981. *Innovation Diffusion: A New Perspective*. London: Methuen.

Burt, R. S. 1987. "Social Contagion and Innovation: Cohesion Versus Structural Equivalence." *American Journal of Sociology* 92:1287-335.

Caldwell, J. 1982. *Theory of Fertility Decline*. New York, New York: Academic Press.

Carlsson, Gosta 1966. "The Decline of Fertility: Innovation or Adjustment Process?" *Population Studies* 20:149-74.

Casterline, John B., Mark R. Montgomery, and Rebecca L. Clark. 1987. "Diffusion Models of Fertility Control: Are There New Insights." PSTC WP 87-06. Brown University, July.

Cavalli-Sforza, L. L. and M. W. Feldman. 1980. *Cultural Transmission and Evolution: A Quantitative Approach*. Princeton, NJ: Princeton University Press.

Chaves, Mark. 1996. "Ordaining Women: The Diffusion of an Organizational Innovation." *American Journal of Sociology* 101(4):840-73.

Cleland, J. and C. Wilson. 1987. "Demand Theories of the Fertility Transition: An Iconoclastic View." *Population Studies* 41:5-30.

Coale, A. J., Presenter. 1973. "The Demographic Transition." International Union of the Scientific Study of Population. Liege: Ordina.

Coale, A. J. and S. C. Watkins. 1986. *The Decline of Fertility in Europe*. Princeton, NJ: Princeton University Press.

Cohen, B. and M. Montgomery. 1997. "Introduction." In *Reevaluating the Link Between Infant and Child Mortality*, edited by M. Montgomery and B. Cohen. New York: National Research Council.

Coleman, J. S. 1990. *Foundations of Social Theory*. Cambridge, MA: Harvard University Press.

Coleman, J. S., E. Katz, and H. Menzel. 1966. *Medical Innovation: A Diffusion Study*. New York: Bobbs Merrill.

Conell, Carol and Samuel Cohn. 1995. "Learning from Other People's Actions: Environmental Variation and Diffusion in French Coal Mining Strikes, 1890-1935." *American Journal of Sociology* 101(2):366-403.

Cressie, N. 1991. *Statistics for Spatial Data*. New York: Wiley.

Davis, K. 1963. "The Theory of Change and Response in Modern Demographic History." *Population Index* 29(4):345-66.

DiMaggio, P. J. and W. W. Powell. 1991. "The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organization Fields." In *The New Institutionalism in Organizational Quantitative Analysis*, edited by P. J. DiMaggio and W.W. Powell. Chicago, Illinois: University of Chicago Press.

Doreian, P. and F. N. Stokman. 1997. *Evolution of Social Networks*. Edited by P. Doreian and F. N. Stokman. Amsterdam: Gordon and Breach.

Durlauf, Steven and James Walker. 1998. "Economic Theory and Diffusion Models." National Research Council. Workshop on Social Processes Underlying Fertility Change in Developing Countries. Washington, D.C., 29-30/January.

Erbring, Lutz and Alice A. Young. 1979. "Individuals and Social Structure: Contextual Effects as Endogenous Feedback." *Sociological Methods and Research* 7(4):396-430.

Evans, R. J. 1991. *Death in Hamburg*. Penguin Books.

Fligstein, Neil. 1985. "The Spread of the Multidivisional Form Among Large Firms, 1919-1979." *American Sociological Review* 50(June):377-91.

Frederiksen, H. 1966. "Determinants and Consequences of Mortality and Fertility Trends." *Public Health Reports* 81:715-27.

Futing Liao, Tim. 1994. "A Theoretical Framework of Collective Action for the Evaluation of Family Planning Programs." *Population Research and Policy Review* 13:49-67.

Galloway, P., E.A. Hammel, and R. D. Lee. 1994. "Fertility Decline in Prussia, 1875-1910: A Pooled Cross-Section Time Series Analysis." *Population Studies* 48(1):135-48.

Granovetter, M. 1973. "The Strength of Weak Ties." *American Journal of Sociology* 78:1360-80.

_____. 1978. "Threshold Models of Collective Behavior." *American Journal of Sociology* 83:1420-43.

Hagerstrand, T. 1967. *Innovation Diffusion as a Spatial Process*. Chicago: University of Chicago Press.

Hamblin, R. L., R. B. Jacobsen, and J. L. L. Miller. 1973. *A Mathematical Theory of Social Change*. New York: Wiley.

Hannan, Michael T. and John H. Freeman. 1977. "The Population Ecology of Organizations." *American Journal of Sociology* 82:929-64.

Hechter, M. 1975. *Internal Colonialism: The Celtic Fringe in British National Development, 1536-1966*. London: Routledge and Kegan Paul.

Hedstrom, Peter. 1994. "Contagious Collectivities: On the Spatial Diffusion of Swedish Trade Unions 1890-1940." *American Journal of Sociology* 99(5):1157-79.

Jenkins, Craig, J. and Craig M. Eckert. 1986. "Channeling Black Insurgency: Elite Patronage and Professional Social Movement Organizations in the Development of Black Movement." *American Sociological Review* 51:812-29.

Katz, Elihu. 1961. "The Social Itinerary of Technical Change: Two Studies on Diffusion of Innovation." In *Studies on Innovation and of Communication to the Public*, edited by Wilber Schramm. Stanford, CA: Stanford University.

Katz, Elihu and Paul F. Lazarsfeld. 1955. *Personal Influence: The Part Played by People in the Flow of Mass Communications*. New York: Free Press.

Knodel, John. 1974. *The Decline of Fertility in Germany*. Princeton, New Jersey: Princeton University Press.

Knodel, J. and E. van de Walle. 1967. "Breast Feeding, Fertility, and Infant Mortality." *Population Studies* 21(2):109-31.

Kohler, H. 1996. "Learning in Social Networks: Contraceptive Choice and Other Technological Dynamics." Paper Presented at the Population Association of America Meetings. New Orleans, May.

Kohler, Hans-Peter. 1998. "Social Interactions and Fluctuations in Birth Rates." Unpublished manuscript.

Kornhauser, William. 1959. *The Politics of Mass Society*. New York: The Free Press.

Laumann, E. O., Marsden P. V., and J. Galaskiewicz. 1977. "Community-Elite Influence Structures: Extension of a Network Approach." *American Journal of Sociology* 83:594-631.

LeBon, Gustave. 1897. *The Crowd*. London: Unwin.

Lesthaeghe, R. J. 1977. *The Decline of Belgian Fertility, 1800-1970*. Princeton, NJ: Princeton University Press.

Lesthaeghe, R. and C. Vanderhoeft. 1998. *Ready, Willing and Able: A Conceptualization of Transitions to New Behavioral Forms*.

Livi-Bacci, M. 1971. *A Century of Portuguese Fertility*. Princeton: Princeton University Press.

_____. 1986. "Social-Group Forerunners of Fertility Control in Europe." In *The Decline of Fertility in Europe*, edited by A. Coale and S. Watkins. Princeton, New Jersey: Princeton University Press.

Mahajan, V. and R. A. Peterson. 1985. *Models for Innovation Diffusion*. Newbury Park, CA: Sage Publications.

Manski, Charles F. 1995. *Identification Problems in the Social Science*. Cambridge, MA: Harvard University Press.

March, James G. and Johan P. Olsen. 1976. *Ambiguity and Choice in Organizations*. Bergen: Universitetsforlaget.

Marsden, P. V. 1981. "Introducing influence processes into a system of collective decisons." *American Journal of Sociology* 86:1203-35.

Marsden, P. 1998. "Diffusion Through Social Networks." National Research Council. Workshop on Social Processes Underlying Fertility Change in Developing Countries. Washington, D.C., 29-30/January.

Marsden, Peter and Noah Friedkin. 1993. "Network Studies of Social Influence." *Sociological Methods and Research* 22(1):127-51.

Marwell, Gerald and Pamela E. Oliver. 1993. *The Critical Mass in Collective Action: A Micro-Social Theory*. Cambridge: Cambridge University Press.

McAdam, Doug. 1982. *Political Process and the Development of Black Insurgency 1930-1970*. Chicago: University of Chicago Press.

_____. 1995. "Initiator and Spin-Off Movements: Diffusion Processes in Protest Cycles." Pp. 217-39 in *Repertoires and Cycles of Collective Action*, edited by M. Traugott. Duke University Press.

McAdam, Doug and Dieter Rucht. 1993. "The Cross National Diffusion of Movement Ideas." American Academy of Political and Social Science.

McKeown, T. 1976. *The Modern Rise of Population*. New York: Academic Press.

Montgomery, Mark and John Casterline. 1993. "The Diffusion of Fertility Control in Taiwan: Evidence from Pooled Cross-Section, Time-Series Models." *Population Studies* 47(3):457-79.

Montgomery, Mark R. and John B. Casterline. 1996. *Social Learning, Social Influence, and New Models of Fertility*. New York: The Population Council.

Montgomery, Mark and Woojin Sik Chung. 1994. "Social Networks and the Diffusion of Fertility Control: The Korean Case." In *Values and Fertility Change*. International Union for the Scientific Study of Population Conference. Sion, February.

Morris, Martina. 1993. "Epidemiology and Social Networks: Modeling Structured Diffusion." *Sociological Methods and Research* 22:99-126.

Moscovici, S. 1985. "Social Influence and Conformity." *The Handbook of Social Psychology* 2(347-412).

Myers, D. J. 1997. "Diffusion Models for Riots and Other Collective Violence." Ph. D. Diss. University of Wisconsin.

Notestein, F. W. 1945. "Population--the Long View." Pp. 36-57 in *Food for the World*, edited by T. W. Schultz. Chicago: University of Chicago Press.

Oberschall, A. 1989. "The 1960 sit-ins: protest diffusion and movement take-off." *Research in Social Movements, Conflict and Change* 11:31-53.

Okun, B. S. 1994. "Evaluating Methods for Detecting Fertility Control: Method and Cohort Parity Analysis." *Population Studies* 48:193-222.

Olson, M. 1965. *The Logic of Collective Action*. Cambridge: Harvard University Press.

Olzak, Susan. 1992. *The Dynamics of Ethnic Competition and Conflict*. Palo Alto: Stanford University Press.

Palloni, Alberto and Hantamalala Rafalimanana. 1997. "The Effects of Infant Mortality on Fertility Revisited: Some New Evidence." Center for Demography and Ecology Working Paper No. 96-27. University of Wisconsin-Madison, Madison, Wisconsin.

Palloni, Alberto and R. Wyrick. 1981. "Mortality Decline in Latin America: Changes in the Structures of Causes of Deaths, 1950-1975." *Social Biology* 28(3-4):187-216.

Pitcher, B. L., R. L. Hamblin, and J. L. L. Miller. 1978. "Diffusion of Collective Violence." *American Sociological Review* 43:23-35.

Piven, Frances Fox and Richard Cloward. 1979. *Poor People's Movements: Why They Succeed, How They Fail*. New York: Vintage.

Potter, Joseph. 1998. "The Dark Side of Diffusion: Increasing Returns and the Persistence of Outmoded Contraceptive Regimes." National Research Council. Workshop on Social Processes Underlying Fertility Change in Developing Countries. Washington, D. C., 29-30/January.

Preston, S. H. 1978. "Introduction." In *The Effects of Infant and Child Mortality on Fertility*, edited by S. H. Preston. New York: Academic Press.

Preston, Samuel. 1980. "Causes and Consequences of Mortality Decline in Less Developed Countries During the Twentieth Century." In *Population and Economic Change in Developing Countries*, edited by Richard E. Easterlin. Chicago, Illinois: University of Chicago Press.

Preston, Samuel H. and Michael R. Haines. 1991. *Fatal Years*. Princeton: Princeton University Press.

Preston, Samuel and E. van de Walle. 1978. "Urban French Mortality in the Nineteenth Century." *Population Studies* 32(2):275-97.

Rogers, Everett M. 1962. *The Diffusion of Innovations*. 1st edition. New York: The Free Press.

_____. 1973. *The Diffusion of Innovations*. 2d ed. New York: The Free Press.

_____. 1983. *Diffusion of Innovations*. New York: Free Press.

_____. 1988. *The Diffusion of Innovations*. 3d ed. New York: The Free Press.

_____. 1995. *The Diffusion of Innovations*. 4th ed. New York: The Free Press.

Rogers, E. M. and D. L. Kincaid. 1980. *Communication Networks: A New Paradigm for Research*. New York: Free Press.

Rosero-Bixby, Luis. 1991. "Interaction Diffusion and Fertility Transition in Costa Rica." Ph. D. Diss., School of Public Health: University of Michigan.

Rosero-Bixby, Luis and John Casterline. 1993. "Modelling Diffusion Effects in Fertility Transition." *Population Studies* 47(1):147-67.

Rosero-Bixby, Luis and John B. Casterline. 1994. "Interaction Diffusion and Fertility Transition in Costa Rica." *Social Forces* 73(2):435-62.

Ryan, Bryce and Neal C. Gross. 1943. "The Diffusion of Hybrid Seed Corn in Two Iowa Communities." *Rural Sociology* 8:15-24.

Sinding, S. and K.O. Mason. 1998. "Diffusion Theories and Population Policies." National Research Council. Workshop on Social Processs Underlying Fertility Change in Developing Countries. Washington, D.C., 29-30/January.

Strang, David. 1991. "Adding Social Structure to Diffusion Models: An Event History Framework." *Sociological Methods and Research* 19:324-53.

Strang, David and Sarah Soule. 1997. *Diffusion in Organizations and Social Movements: From Hybrid Corn to Poison Pills*. Technical Report 9702.

Strang, David and Nancy B. Tuma. 1993 . “Spatial and Temporal Heterogeneity in Diffusion.” *American Journal of Sociology* 99:614-39.

Tarrow, Sidney. 1994. *Power in Movement*. Cambridge: Cambridge University Press.

Tilly, Charles. 1978. *From Mobilization to Revolution*. New York: McGraw-Hill.

Tolnay, Stewart E., Glenn Deane, and E. M. Beck. 1996. “Vicarious Violence: Spatial Effects on Southern Lynchings, 1890-1919.” *American Journal of Sociology* 102(3):788-815.

Valente, Thomas W. 1995. *Network Models of the Diffusion of Innovations*. Cresskill, NJ: Hampton Press.

Van de Walle, F. 1986. “Infant Mortality and the European Demographic Transition.” Pp. 201-33 in *The Decline of Fertility in Europe*, edited by A. J. Coale and S. C. Watkins. Princeton, New Jersey: Princeton University Press.

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