Adoption of Communication Technologies and the Evolution of Communication Networks in Organizations

Noshir S. Contractor

Carolyn Leveque

The diffusion of innovations has been studied from a variety of perspectives and in a variety of contexts. Early studies in rural sociology and marketing examined the extent to which the likelihood of adoption was predicted by individuals' characteristics such as gender, race, age, income, and education (Rogers, 1983). The early tradition of innovation diffusion research were typically concerned with "when did whom adopt what and what is the difference between early and late adopters" (Carley, 1990, p. 208). These concerns were limited on two counts. First, there was a preponderance of studies that focused on the initial phases of the adoption process. This limitation was particularly true for cross-sectional case studies which ignored the long-term dynamics of the diffusion process. Second, there was an over-emphasis on the individual characteristics of adopters without adequate consideration of the social context of adoption. By focusing on individuals characteristics, and ignoring their communication networks, researchers assumed that individuals made adoption decisions in a social vacuum.

The present study attempts to further our understanding of the adoption process by addressing both of these limitations. Specifically, we focus on the evolution of communication networks in organizations resulting from the adoption process and takes into account the influence of individuals' communication networks on their adoption decisions. We begin with a critical review of attempts made by past research in social and organizational contexts to address these limitations. Next, we discusse why studying the adoption process of communication technologies are qualitatively different from the diffusion of other innovations. Given these differences, we offer Burt's (1982) Structural Theory of Action as a particularly appropriate framework to study the influence of the adoption process of a communication technology on the evolution of organizational communication networks. We conclude with a report on a simulation based on the Structural Theory of Action. The simulation provides hypotheses relating the temporal effects of communication networks and individual characteristics on the adoption process.

Review of network research on the adoption process

The importance of the network perspective was first introduced by Coleman, Katz, and Menzel (1957) in their classic study of the diffusion of a new antibiotic drug among physicians in four midwestern communities. Coleman et al. found that the timing and likelihood of doctors adopting the drug was better predicted by their position in the physicians' communication network than their individual characteristics. They concluded that actors tended to adopt the innovation if the colleagues they had communication links with made the choice to adopt. In the past decade, several studies have attempted to explain adoption in terms of individuals' personal preferences and their communication networks (e.g., Anderson & Jay, 1985; Johnson, 1986; Kara-Murza, 1981; Markus, 1990; Rice, Grant, Schmitz, & Torobin, 1990; Wohlert & Grant, 1992). In a review essay, Rogers (1987) suggests that relational variables serve as a "turbo-charger" for explaining individuals' adoption of innovations. For instance, Anderson and Jay (1985) examined the adoption of a computerized information system by physicians. They found network variables to be predictive of adoption above and beyond that which was explained by individual attribute variables.

The early literature pertaining to the adoption of innovations in organizational contexts was also subject to similar criticisms (Baldridge & Burnham, 1975). In the organizational context, the criticism was directed at the lack of attention to the influence of structural and organizational level variables on the adoption process. In response to these criticisms, there have been several studies investigating the influence of formal structural and organizational variables on the adoption process. These include, for example, size (Kimberly & Evanisko, 1981), distribution and availability of resources (Baldridge & Burnham, 1975), differentiation and complexity (Pierce & Delbecq, 1976), environmental uncertainty (Pierce & Delbecq, 1976), absorptive capacity (Cohen & Levinthal, 1990), decentralization, communication channels and information sources (Fidler & Johnson, 1984; Nilakanta & Scamell, 1990; Lind & Zmud, 1991; Albrecht & Ropp, 1984; Miller & Monge, 1985; Monge, Cozzens, & Contractor, 1992), organizational culture (Feldman, 1989), and organization type (Ghosal & Bartlett, 1988; Damanpour & Evan, 1984). Damanpour (1991) conducted a meta-analysis of 23 empirical studies that investigated the determinants of innovation. He found that there were:

> "(1) positive associations between innovation and specialization, functional differentiation, professionalism, managerial attitude toward change, technical knowledge resources, administrative intensity, slack resources, and external and internal communication; (2) a negative association between innovation and centralization; and (3) nonsignificant associations between innovation and formalization, managerial tenure, and vertical differentiation (p. 569).

The determinants of innovation reviewed in this meta-analysis can be classified into four categories - individual-level variables such as professionalism, managerial attitude toward change, and managerial tenure; formal structural variables such as specialization, functional differentiation, administrative intensity, centralization, formalization, and vertical differentiation; resource variables such as technical knowledge resources and slack resources; and communication variables including gross measures of the volume of internal and external communication. Damanpour's literature review of the determinants of innovation underscores the lack of empirical studies that investigate the extent to which the emergent communication network influences organizational members' decision to adopt an innovation.

To summarize, the majority of research in organizational and other social contexts examine the extent to which adoption is influenced by individual-level characteristics, the organization's formal structural characteristics and its resources. Further, these studies typically make inferences based on data collected at one point in time. While scholars have called for examining the influence of communication networks on the adoption process, there have been few empirical studies that have incorporated network determinants; even fewer have examined the influence of evolving networks on the dynamics of adoption. While our discussion so far has considered innovations in general, the next section focuses on the role of evolving communication networks in influencing adoption decisions about communication technologies.

Adoption of a Communication Technology

Innovations can take several forms including changes in structure, technology, product, process or administrative policy (Damanpour, 1991; Rogers, 1983). However, as Markus (1990) notes, the adoption of a new communication technology is qualitatively different from many other innovations. While an individual can independently accrue payoffs by adopting some innovations, the benefits of adopting a new communication technology can only be realized if it is also adopted by others with whom the individual is interdependent. "At a minimum, two users are necessary for either to receive benefits" (Markus, 1990, p. 195). As such, the adoption of a communication technology is necessarily a collective action that requires individuals to take into consideration not only their own interests, but also the interests of others in their communication network with whom they are interdependent (Fulk, Schmitz, & Steinfield, 1990; Oliver, Marwell, & Teixeira, 1985). Further, their adoption of a new communication technology offers the potential of new communication channels and increased access to other members in their communication network thereby altering the communication network itself. Hence, the adoption of communication technologies must be viewed as a recursive process - individuals' decision to adopt a communication technology is influenced by the interests of others in their communication network; further, the communication network is itself evolving as a result of individuals decisions to adopt a new communication technology (Contractor & Eisenberg, 1990). The next section describes Burt's (1982) Theory of Structural Action that explicitly takes into account this recursive process.

The Structural Theory of Action

The central premise of Burt's (1982) Structural Theory of Action is that actors are purposive under structural constraint. In the present study, action is defined as an individual's adoption of a new communication technology, and structure refers to the individual's communication network. The theory is framed as a bridge between normative and atomistic conceptualizations of social action. An atomistic perspective assumes that individuals' adoption decisions are evaluated independently without reference to others; a normative perspective assumes that actions are evaluated interdependently through the socializing processes that situate them within a system of other social actors (Burt, 1982).

Burt's Structural Theory of Action, however, posits that individuals evaluate the utility of adopting partly in consideration of their personal preferences (or liking), and partly in regard to the interests of other actors in the social system. Thus, action and structure are considered simultaneously as mutually constituting and constitutive: ongoing patterns of communication are both conditions and consequences of adoption decisions.

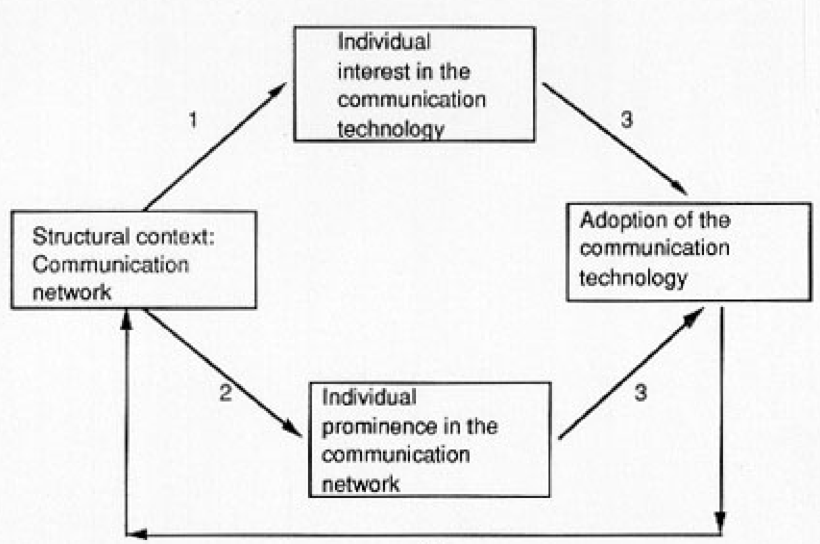
> Actions are . . . a joint function of actors pursuing their interests to the limit of their ability where both interests and ability are patterned by social structure. Finally, actions taken under social structural constraint can modify social structure itself and these modifications have the potential to create new constraints to be faced by actors within the structure (Burt, 1982, p. 9).

Burt (1982) describes this recursive process between structure and action in terms of a "causal cycle" (p. 9). Figure 1 is an adaptation of his model to examine the adoption process of a new communication technology. The causal links posited in this model are enumerated in Figure 1. In Link 1, the theory posits that individuals' interest in the new communication technology is shaped by personal preferences (or liking) and the interests of others with whom the individual communicates. Burt describes an individual's interest in a new communication technology in terms of a contagion model:

$$I_i = b_l(L_i) + b_s \sum_{j=1}^{N} C_{ij} I_j \quad i \neq j \qquad (1)$$

where, I_i is individual i's interest in the new communication technology, L_i is individual i's personal preference (or liking) towards the technology, and C_{ij} is the amount individual i communicates with individual j. b_l and b_s describe the relative influences of personal preference (or liking) and social influence respectively on the individuals' interest in the new communication technology.

Figure 1. Adoption of communication technologies based on Burt's Structural Theory of Action.



The first term on the right hand side of Equation 1 describes the extent to which individuals' interest in a new communication technology is influenced by their own personal preference (or liking). The second term on the right hand side of Equation 1 describes the extent to which an individual's interest is influenced by the interests of the remaining N-1 individuals in the network, weighted by the amount the individual communicates with each of these individuals.

The relative importance of the first and second terms on the right hand side of Equation 1 are determined by the context in which the "contagion" occurs. Individuals are more likely to be socially influenced by others in ambiguous situations (Moscovici, 1976; Rice, in press; Thomas & Griffin, 1983; Woelfel & Haller, 1971). Hence in situations of high uncertainty, such as the introduction of a new communication technology, we would expect that individuals' interests are more likely to be shaped by others than by their own personal preferences. That is, we would expect that the weighting coefficient b_l will be much smaller than b_s.

Link 2 in Figure 1 describes the extent to which an individual is constrained (or enabled) to take action as a consequence of their position in the communication network. An individual who is more prominent in the communication network has the ability to draw upon the network for resources and is therefore less constrained in adopting a new communication technology (Markus, 1990; Oliver et al., 1985). An individual's prominence is defined as the extent to which s/he receives communication from other prominent individuals in the network. Hence, P_i, the prominence of individual i, is given by:

$$P_i = \sum_{j=1}^{N} P_j C_{ij} \quad i \neq j \qquad (2)$$

Computationally, the prominence of individuals is the first eigenvector of the normalized communication network (Knoke & Kuklinski, 1982).

The two links labeled Link 3 in Figure 1 refer to Burt's (1982) argument that individuals' decisions to adopt a new communication technology is a multiplicative function of their interests in the new communication technology (described by the contagion model) and their ability (as reflected by their prominence in the communication network). Hence, A_i, the likelihood of individual i adopting a new communication technology is given by:

$$A_i = I_i * P_i \qquad (3)$$

Equation 3 underscores the dual influence of interest <u>and</u> ability in the adoption process. According to the Structural Theory of Action, an individual who has considerable interest in the new communication technology but low prominence in the communication network, or low interest in the technology but substantial prominence in the network, are <u>not</u> likely to adopt the new communication technology.

Finally, Link 4 describes the impact of adopting a new communication technology on the extant communication network. As mentioned earlier, if two individuals were to both adopt a new communication technology, there now exists a communication link between them. The addition of a new communication link to the extant communication network is given by:

$$C_{ij} = 1 \text{ if, and only if, individuals i and j adopt the new technology} \qquad (4)$$

Since the model articulated in Figure 1 is cyclical, the recursive process is repeated. To the extent that individuals' adoption of the new communication technology has changed the communication network, individuals' interests and ability, which are patterned by the communication network, will also be modified. This change will, in turn, result in the likelihood of additional individuals adopting the new communication technology. The process will repeat itself until the point where no new individuals are adopting the technology, resulting in a stable communication network.

In this section we have offered Burt's Structural Theory of Action as an appropriate and explicit model to study individuals' adoption of a new communication technology. The theory posits that action (the adoption of a new communication technology) is influenced by, and in turn influences, the communication structure. The model offers specific generative mechanisms for the mutual influence. In the next section, we consider the adoption dynamics that are implied by the Structural Theory of Action.

<u>Network Evolution Implied by the Structural Theory of Action</u>

Unlike some social theories that offer verbal descriptions that "are (1) richly evocative and (2) highly abbreviated" (Hanneman, 1988, p. 23), Burt's (1982) Structural Theory of Action offers an unambiguous formulation relating structure and action. It is important to recognize that the causal links posited by the theory (see Figure 1 and Equations 1 through 4) are generative mechanisms that are repeated in a cyclical fashion. Since the process is cyclical, the relationships proposed by the Theory of Structural Action are non-linear. While it is possible for scholars to articulate such non-linear mechanisms, it is not easy for the human intellect to mentally construe the dynamics of adoption implied by these mechanisms (Poole, 1990). From a computational standpoint, this is because non-linear relationships often do not have closed form solutions and are therefore analytically intractable (Contractor, 1994).

Scholars have suggested that the adoption process for innovations that require collective action, such as the adoption of a communication technology, will be influenced by the initial heterogeneity of individuals' interests and their resources (Markus, 1990; Oliver et al., 1985). However, it is not possible to deduce hypotheses about the influence of interest and resource heterogeneity on the dynamics of adoption simply by inspecting the generative mechanisms proposed by the Structural Theory of Action. Social network researchers (e.g., Leenders, 1993; Stokman & Zeggelin, 1992; Zeggelink, 1993, 1994) have offered a cogent rationale for the use of computer simulations in similar situations. Recent developments in computational science make it possible to use simulations as a tool to observe the network evolution implied by the Structural Theory of Action (Hanneman, 1988; Whicker & Sigelman, 1991).

In the present study, simulations were used to examine the extent to which the adoption characteristics, as implied by the Structural Theory of Action, would be influenced by two initial conditions - (i) the heterogeneity in individuals' initial interests in the new communication technology, and (ii) the heterogeneity of resources available to individuals. Adoption characteristics are defined as the total number of new communication links resulting from the adoption of the new communication technology, and the time it takes for them to emerge. Heterogeneity of interests is defined as the variation in the degree to which individuals perceive they can benefit from adopting the new communication technology. Heterogeneity of resources is defined as the variation in the degree to which individuals have the resources required to adopt the technology (Markus, 1990). The next section presents four research questions that consider the impacts of these two initial conditions on the evolution of the networks and the adoption process.

Research Questions

The first two research questions investigated in this study pertain to the manner in which the adoption characteristics are influenced by heterogeneity in individuals' interest in the communication technology. As mentioned above, interest heterogeneity represents the variation in individuals' perceptions that they can benefit from adopting the new communication technology. Operationally, it is defined as the standard deviation in individuals' initial interests in the technology. Specifically, we seek to explore if groups that have a high standard deviation in their initial interests in the communication technology will exhibit adoption characteristics that are significantly different from groups where there is greater convergence in interests. Links 1 and 2 of the generative mechanisms (Figure 1, Equations 1 and 2) posit that individuals' decision to adopt is shaped, in part, by the interests of other individuals in the communication network. However, it is not immediately apparent how, if at all, the dynamics of adoption will be systematically influenced by variation among individuals' interests in the new communication technology.

Researchers and practitioners interested in collective action have noted that interest heterogeneity influences the level and speed with which individuals participate in collective action (Markus, 1990). In an extension of Coleman's (1973) model of collective decision making, Marsden (1981) found that the nature and magnitude of system level effects are contingent upon the pattern of interest differentiation in the influence network. Oliver et al (1985) found the heterogeneity of interests among community members increased the likelihood of collective action. In the absence of conclusive theoretical or empirical evidence we propose the following two research questions:

RQ1: What effect, if any, does initial interest heterogeneity have on the total number of individuals adopting a new communication technology?

RQ2: What effect, if any, does initial interest heterogeneity have on the time it takes for individuals to adopt a new communication technology?

The next two research questions assess the effect, if any, of resource heterogeneity on the adoption dynamics, as implied by the Structural Theory of Action. As mentioned earlier, resource heterogeneity is defined as the variation in the degree to which individuals have the resources required to adopt the technology (Markus, 1990). Individuals prominent in the communication network have the ability to draw upon the network for resources, and are therefore less constrained in adopting a new communication technology. Hence, heterogeneity of resources among individuals can be measured by examining heterogeneity in their levels of prominence in the communication network. In a heterogeneous network, a few individuals will be very prominent while others would have low prominence. Conversely, a network in which all individuals are equally prominent is homogeneous. Knoke and Burt (1983) proposed the following information-theoretic measure as an operational definition of resource heterogeneity, RH :

$$\mathbf{RH} = \frac{\sum_{i=1}^{N}\left[\left(\frac{P_j}{P_m}\right) * \ln\left(\frac{P_j}{P_m}\right)\right]}{N * \ln[N]} \qquad (5)$$

where, P_i is the prominence of individual i, P_m is the mean prominence of all individuals in the network, N is the number of individuals in the network, and ln is the natural logarithm. Resource heterogeneity, as operationalized here, is analogous to network centralization (Freeman, 1978) and network prominence (Knoke & Burt, 1983).

In general terms, we seek to examine if, according to the Structural Theory of Action, groups that are more heterogeneous in their resources will exhibit adoption characteristics that are significantly different from groups that are less heterogeneous. Specifically, we consider the effect of resource heterogeneity on the number of new communication links made possible by individuals adopting the new communication technology, and the time it takes for them to emerge. Links 2 and 3 of the generative mechanisms (Figure 1, Equations 2 and 3) posits that the likelihood of adoption is influenced by an individual's prominence in the network. However, it is not immediately apparent if the network's adoption patterns will be systematically influenced by variation among individuals' prominence scores.

The relationship between resource heterogeneity and adoption has been of considerable interest to theorists and practitioners interested in collective action. Marwell, Oliver and Prahl (1988) examined the collective efforts of individuals in suburban communities to organize electoral support for local propositions. They observed that collective action was more likely to occur in heterogeneous networks where one (or a few) prominent individual(s) were able to assume leadership and rally their less prominent supporters. However, they note that in addition to being prominent in the heterogeneous communication network, these leaders were "selected" in part because of their enthusiasm to implement the collective action. In the present study no such assumption is made. It is not realistic to assume that individuals who have the greatest interest in a new communication technology will also be most prominent in the communication network. Given the lack of specific theoretical or empirical evidence we propose the following two research questions:

RQ3: What effect, if any, does initial network heterogeneity have on the total number of new communication links resulting from the adoption of a new communication technology?

RQ4: What effect, if any, does initial network heterogeneity have on the time it takes for new links to be created as a result of adopting a new communication technology?

We began the previous section by noting that, notwithstanding the clarity of the generative mechanisms explicated in Burt's Structural Theory of Action, it is not possible to deduce hypotheses about the dynamics of adoption simply by inspecting these mechanisms. We argued that simulations are especially appropriate to help researchers deduce hypotheses that are implied by, but not immediately evident from, an examination of the the Structural Theory of Action. In this section, we proposed four research questions relating the influence of initial interest and resource heterogeneity on the adoption process. In the next section, we present a methodology, using simulations, to answer these research questions. The results of the simulation provide hypotheses deduced from the Structural Theory of Action that must then be empirically tested.

Methods

Data Generation

The model used for the simulation includes five elements: (i) the communication network structure, (ii) individuals' interest in the new communication technology, (iii) individuals' prominence in the communication network, (iv) their disposition to adopt, and (v) their decision to adopt the new communication technology. Data was generated for two of these elements - the initial communication network structure and individual's initial interest in the communication technology.

Initial Communication Network Structure. The initial communication network structure was operationalized as a binary asymmetric communication network of 20 individuals. 400 such networks were generated using Monte Carlo techniques (Burt, 1991). All 400 networks were specified to have a density of 0.5. That is, in each network the total number of communication links were 190, half the total number of possible 380 links. In 200 of the networks generated, resource heterogeneity was specified to be high (Mean = -.85; s.e. = .001). In these networks, a few of the members were significantly more prominent than others. In the remaining 200 networks, resource heterogeneity was specified to be low (Mean = -.99; s.e. < .0001); there was not much variation in individuals' prominence scores in these networks. Manipulation checks confirmed that there was a significant difference (t=262.68, $p < .001$) in resource heterogeneity between networks created in these two conditions.

Individual's initial interest in the communication technology. Individuals' initial interest in the technology was operationalized as a 20x1 vector. 400 vectors were generated, with each vector containing the interest scores for individuals in one group of 20 individuals. Each individual's level of interest in the technology was allowed to vary between 1 (low interest) and 10 (high interest). For each vector, the mean interest among the individuals was held constant at 5.0. In 200 of the vectors generated, the standard deviation among the individuals' interest in the new communication technology was held constant at a high value (Mean = 1.39, s.e. = .008); for the remaining 200 vectors the standard deviation among individuals' interest in the new communication technology was restricted to a low value (Mean = 0.40; s.e. = .003). Manipulation checks confirmed that there was a significant difference between vectors specified as having high and low interest heterogeneity (t=117.74, p < .001).

Design of the Simulation

The communication network matrices and individual interest vectors generated were used to study the adoption process under four conditions representing high and low levels of resource and interest heterogeneity (Table 1). 300 simulations were executed, using combinations of the 200 matrices and 100 vectors, in each of the four conditions. Hence, a total of 1,200 simulations were executed.

Table 1 about here

Execution of simulation

Given the initial communication matrices and actor interest vectors, the simulation was executed using Mathematica (Wolfram, 1991) on a supercomputer. Each iteration of the simulation progressed through five steps.

Step 1. The first step was to compute the extent to which individuals were enabled (or constrained) to take action based on their position in the communication network (Link 2 in Figure 1). As discussed earlier, an individual's prominence in the communication network is a measure of this ability (or constraint). Hence, in Step 1, a vector of prominence scores were computed for all of the individuals using Equation 2.

Step 2. The second step was to determine individuals' likelihood of adoption based on their interests in the communication technology and their prominence in the communication network (Link 3 in Figure 1). A vector measuring individuals' likelihood of adoption was computed by multiplying their interests in the technology and their prominence in the communication network (see Equation 3).

Step 3. In this step individuals' likelihood to adopt were transformed into a decision about adoption. The likelihood of adoption vector was dichotomized at a cutoff value of three. Substantively, this decision rule implies that if an actor's interest was still above a score of three after taking into account structural constraint defined by that actor's position, the actor "chooses" to adopt the technology. The result is a binary adoption vector.

Step 4. The next step was to determine the effect of individuals adopting the new communication technology on the existing communication network (Link 4 in Figure 1; Equation 4). A new communication link was added between two individuals, if and only if (1) both individuals had decided to adopt the new communication technology, and (2) a prior link did not exist between the actors.

Step 5. The final step determined the extent to which individuals' initial interests in the technology were modified by the interests of others in the communication network (Link 1 in Figure 1). This effect was determined by the contagion model (Equation 1). Thus, each individual's interest in the technology is influenced by their own initial interest and the interest levels of others with who s/he has direct links in the communication matrix. In the present study, the b_I and b_S weighting coefficients in Equation 1 were specified at 0.2 and 0.8 respectively. That is, 80% of an individual's interest in the technology was patterned by social influence with others, while 20% reflects the individual's initial interest.

The simulation proceeded through multiple iterations, until there were no new individuals adopting the communication technology and the communication network had stabilized. In all cases, the adoption process had stabilized within five iterations.

Analysis

The research questions considered the extent to which adoption characteristics were influenced by variations in interest and resource heterogeneity. Adoption characteristics were operationalized as (i) the total number of new links added to the communication network, and (ii) the number of new links that were added to the network at each point in time. Interest heterogeneity was operationalized as the standard deviation in individuals' initial interests in the technology. Resource heterogeneity was operationalized as the variation in individuals' prominence in the network. That is, variation in individuals' ability to draw upon their communication network for resources (Equation 5, discussed earlier).

First, *t*-tests were were conducted to examine if groups that had high/low heterogeneity in interests and resources varied in their adoption characteristics. Next, regression analyses were conducted to assess the extent to which the number of links adopted by groups across all points in time, and at each point in time, were influenced by their interest and resource heterogeneity.

Results

The means and standard deviation of new links in each of the four conditions are shown in Table 2. The average number of new links added to the communication network across all groups was 48.70 (s.d. = 43.47). The number of new links added ranged from 2 to 164. Groups with low initial interest heterogeneity added an average of 48.79 (s.d. = 45.18) new links, while groups with high initial interest heterogeneity added an average of 48.62 (s.d. = 41.76) new links. t-tests revealed that groups with low and high interest heterogeneity did not differ in the number of new links added (t=-.07, p > .05).

Groups with low initial resource heterogeneity added an average of 87.87 (s.d. = 27.20) new links, while groups with high initial resource heterogeneity added an average of 10.12 (s.d. = 4.63) new links. t-tests revealed that groups with low and high resource heterogeneity varied significantly in the number of new links added (t=-68.36, p < .001).

Table 2 about here

The results of the regression analysis are shown in Table 3. The results indicate that the total number of new links adopted by a group as a result of adopting the communication technology was not significantly predicted by the group's initial interest heterogeneity (b = 0.94, n.s.), but was significantly predicted by their initial resource heterogeneity (b = -557.89, p < .01). That is, groups with varying initial interest heterogeneity were not likely to differ in their overall adoption of a new communication technology, but groups with low resource heterogeneity were less likely to adopt the technology.

Table 3 about here

The regression analyses conducted at intermediate points during the adoption process provide further insights (Table 3). Even though, initial interest heterogeneity was not a significant predictor of the total number of new links added, it was a significant predictor of the number of new links added at each of the intermediate points in time (Times 2, 3, 4, and 5). Specifically, groups with high initial interest heterogeneity were less likely to adopt new links at Time 2, but were more likely to adopt the technology at Times 3, 4, and 5. Further, resource heterogeneity was a significant negative predictor of adoption at each of the intermediate points in time.

Discussion

The results of the simulation suggest that while initial interest heterogeneity does not influence the total number of new links emerging from the adoption process, it does influence when the new links are added to the network. Groups with low interest heterogeneity are more likely to be early adopters of the communication technology, while groups with high interest heterogeneity are slower in adopting the technology. Further, the results of the simulation suggest that groups with high resource heterogeneity are always less likely to adopt new communication technologies.

It must be noted that the results of the simulation do not necessarily reflect empirically validated data on the evolution of networks. The purpose of this study was to deduce specific hypotheses about the evolution of networks from Burt's Structural Theory of Action. Hence the results of this study offer hypotheses that must be tested empirically. Empirical support for these hypotheses would indicate that the non-linear generative mechanisms proposed by the Structural Theory of Action are not falsified.

There are at least four aspects of the current dynamic formulation of Structural Theory of Action that can be addressed in future simulations. First, the model proposed in this study assumes that individuals' interest in a new technology are influenced by the interests of others with who they have direct communication links (Equation 1). One alternative contagion mechanism, suggested by Burt (1987), is that individuals' interests are influenced by those with who they are structurally equivalent. Individuals are structurally equivalent with those who have similar communication patterns, even if they do not have any direct communication with each other (Burt, 1987). Another alternative contagion mechanism is that individuals' interests are influenced, not by those with who they communicate, but by those who are prominent in the network. That is, an individual would be influenced by an emergent leader, even if the two do not communicate directly or share similar communication patterns. Future research can execute simulations based on these three competing mechanism of the contagion process. If the adoption characteristics deduced from these mechanisms vary, empirical studies would serve to validate one or the other of these contagion mechanisms.

Second, the present study made the limiting assumption that, at each stage, 80% of the individuals' interests were patterned by their social influences, while 20% was informed by their prior interests. That is, the weighting coefficients b_l and b_s (in Equation 1) were specified as 0.2 and 0.8

respectively. This assumption is plausible, given that individuals are more influenced by others in uncertain contexts, such as the introduction of a new communication technology. However, additional simulations must be executed to assess the effects of changing the relative weighting of social influences and personal preferences on the adoption processes.

Third, the weighting coefficients b_I and b_S (in Equation 1) used in the present study were assumed to be constant across individuals and across time. A more refined model could advance Burt's Structural Theory of Action, by positing explicitly a model where (i) some individuals are more or less likely to be influenced by others, and (ii) the relative importance of social influences over personal preferences are time-dependent, increasing (or diminishing) over the course of the adoption process. Fourth, the present simulation was conducted on groups of size 20. Additional simulations must be conducted to assess if changes in the size of the groups result in qualitative changes in the adoption process. Finally, the statistical analyses of the results from the simulation are necessarily suspect given the dependence structures in the data. Hence further research in this area should consider adopting statistical techniques that address these concerns (Snijders, 1994; Wasserman & Faust, 1994)

The approach demonstrated in this study can be used to refine, make more explicit, and even contrast predictions made by current theoretical perspectives on the use and adoption of communication technologies in organizations. Several recent theorists (Contractor & Eisenberg, 1990; Fulk, Schmitz, & Steinfield, 1990; Markus, 1990; Poole & DeSanctis, 1990) have adopted an emergent perspective to study the adoption of new communication technologies in the context of evolving organizational communication networks. Each propose a set of generative mechanisms to explain the manner in which users influence, and are influenced, by others' perceptions of the media and the norms surrounding its use. The simulation methodology used in this study can help extend these theoretical developments in three ways. First, model-building through the design and execution of computer simulations forces one to make theories and their underlying assumptions more explicit before moving into the validation phase of hypotheses testing in organizational settings (Hanneman, 1988). Second, the methodology used in this study demonstrates the ability to subsume multiple levels of analysis within an internally consistent and coherent framework (Knoke & Kuklinski, 1982). Finally, the analysis of the simulation data offers an opportunity to parse out the differential and combined effects of individual and structural determinants on individuals' perceptions and use of the media (Meyer & Goes, 1988). That is, the results of the simulation can help researchers identify differences in the initial conditions that make a difference in the evolution of communication networks. Hence, this study serves as an exemplar for researchers attempting to deduce hypotheses that are consistent, but not intuitively apparent, from their theoretical perspectives.

References

Albrecht, T.L., & Ropp, V.A. (1984). Communicating about innovation in network of three U.S. organizations. Journal of Communication, 17, 78-91.

Anderson, J. G., & Jay, S. J. (1985). The diffusion of medical technology: Social network analysis and policy research. Social Quarterly, 26, 49-64.

Baldridge, J.V., & Burnham, R.A. (1975). Organizational innovation: Individual,organizational, and environmental impacts. Administrative Science Quarterly, 20, 165-176.

Burt, R.S. (1982). Toward a Structural Theory of Action: Network Models of Social Structure, Perception, and Action. New York: Academic Press.

Burt, R.S. (1987). Social contagion and innovation: cohesion versus structural equivalence. American Journal of Sociology, 92, 1287-1335.

Burt, R. S. (1991). STRUCTURE Version 4.2 [Computer Program]. New York: Center for the Social Sciences, Columbia University.

Cohen, W.M., & Levinthal, D.A. (1990). Absorptive capacity: A new perspective on learning and innovation. Administrative Science Quarterly, 35, 128-152.

Coleman, J.S. (1973). The Mathematics of Collective Action. Chicago: Aldine.

Coleman, J.S., Katz, E., & Menzel, H. (1957). The diffusion of innovation among physicians. Sociometry, 20, 253-270.

Contractor, N. (1994). Self-organizing systems perspective in the study of organizational communication. In B Kovacic (Ed.) New Approaches to Organizational Communication (pp. 39-65).Albany, NY: SUNY Press.

Contractor, N. S., & Eisenberg, E. M. (1990). Communication networks and new media in organizations. In J. Fulk and C.W. Steinfield (Eds.), Organizations and Communication Technology (pp. 143-172). Newbury Park, CA: Sage.

Damanpour, F. (1991). Organizational innovation: A meta-analysis of effects of determinants and moderators. Academy of Management Journal, 34, 555-590.

Damanpour, F., & Evan, W.M. (1984). Organizational innovation and performance: The problem of "organizational lag." Administrative Science Quarterly, 29, 392-409.

Feldman, S.P. (1989). How organizational culture can effect innovation. Organizational Dynamics, 17, 57-68.

Fidler, L.A., & Johnson, J.D. (1984). Communication and innovation implementation. Academy of Management Review, 9, 704-711.

Freeman, L. (1978). Centrality in social networks: Conceptual clarification. Social Networks, 1, 215-239.

Fulk, J., Schmitz, J., & Steinfield, C.W. (1990). A social influence model of technology use. In J. Fulk and C.W. Steinfield (Eds.), Organizations and Communication Technology (pp. 117-140). Newbury Park, CA: Sage.

Ghoshal, S., & Bartlett, C.A. (1988). Creation, adoption, and diffusion of innovations by subsidiaries of multinational corporations. Journal of International Business Studies, 365-388.

Hanneman, R. A. (1988). Computer-assisted theory building: Modeling dynamic social systems. Newbury Park, CA: Sage.

Johnson, J. C. (1986). Social networks and innovation adoption: A look at Burt' use of structural equivalence. Social Networks, 8, 343-364.

Kara-Murza, S. G. (1981). Problems in studying the diffusion of technological innovations in science. Science of Science, 8, 343-364.

Kimberly, J.R., & Evanisko, M.J. (1981). Organizational innovation: The influence of individual, organizational, and contextual factors on hospital adoption of technological and administrative innovations. Academy of Management Journal, 24, 689-713.

Knoke, D., & Burt, R.S. (1983). Prominence. In R.S. Burt and M.J. Minor (Eds.), Applied Network Analysis: An Introduction, (pp. 195-222). Beverly Hills, CA: Sage.

Knoke, D., & Kuklinski, J.H. (1982). Network Analysis. Newbury Park, CA: Sage.

Leenders, R. (1993). Modeling dynamic dependence between network structure and actor characteristics. Paper presented at the Third European Conference on Social Network Analysis, Munich, Germany.

Lind, M.R., & Zmud, R.W. (1991). The influence of a convergence in understanding between technology providers and users on information technology innovativeness. Organization Science, 2, 195-217.

Markus, M.L. (1990). Toward a "critical mass" theory of interactive media. In J. Fulk and C.W. Steinfield (Eds.), Organizations and Communication Technology (pp. 194-218). Newbury Park, CA: Sage.

Marsden, P.V. (1981). Introducing influence processes into a system of collective decisions. American Journal of Sociology, 86, 1203-1235.

Marwell, G., Oliver, P.E., & Prahl, R. (1988). Social networks and collective action: A theory of critical mass III. American Journal of Sociology, 94, 502-395.

Meyer, A.D., & Goes, J.B. (1988). Organizational assimilation of innovations: A multilevel contextual analysis. Academy of Management Journal, 31, 897-923.

Miller, K.I., & Monge, P.R. (1985). Social information and employee anxiety about organizational change. Human Communication Research, 11, 365-386.

Moscovici, S. (1976). Social influence and social change. London: Academic Press.

Monge, P. R., Cozzens, M. D., & Contractor, N. S. (1992). Communication and motivational predictors of the dynamics of organizational innovation. Organization Science , 3, 250-274.

Nilakanta, S., & Scamell, R.W. (1990). The effect of information sources and Communication channels on the diffusion of innovation in a data base development environment. Management Science, 36, 24-40.

Oliver, P. E., Marwell, G., & Teixeira, R. (1985). A theory of critical mass I: Interdependence, group heterogeneity, and the production of collective action. American Journal of Sociology, 91, 522-556.

Pierce, J.L., & Delbecq, A.L. (1976). Organization structure, individual attitudes and innovation.

Poole, M. S. (1990, February). A Turn of the wheel: The case for a renewal of systems inquiry in organizational communication research. Paper presented at the Arizona State University Conference on Organizational Communication, Tempe, AZ.

Poole, M. S., & DeSanctis, G. (1990). Understanding the use of group decision support systems: The theory of adaptive structuration. In C. Steinfield & J. Fulk (Eds.), Organizations and communication technology (pp. 175-195). Newbury Park, CA: Sage.

Rice, R. E. (in press). Using network concepts to clarify sources and mechanisms of social influence. In G. Barnett, & W. Richards, Jr. (Eds.), Advances in Communication Network Analysis. Norwood, NJ: Ablex.

Rice, R. E., Grant, A., Schmitz, J., & Torobin, J. (1990). Individual and network influences on the adoption and perceived outcomes of electronic messaging. Social Networks, 12, 27-55.

Rogers, E.M. (1983). Diffusion of Innovations (3rd ed.). New York: Free Press.

Snijders, T. A. B. (May, 1994). Methods for longitudinal social network data: Review and recent developments. Paper presented at the 5th Tartu Conference on Multivariate Statistics, Tartu, Estonia.

Stokman, F. N., & Zeggelink, E. P. H. (June, 1993). A dynamic access model in policy networks. Paper presented at the Third European Conference on Social Network Analysis, Munich, Germany.

Thomas, J., & Griffin, R. (1983). The social information processing model of task design: A review of the literature. Academy of Management Review, 8, 672-682.

Wasserman, S., & Faust, K. (1994). Social Network Analysis: Methods and Applications. Cambridge, UK: Cambridge University Press.

Whicker, M.L., & Sigelman, L. (1990). Computer Simulation Applications: An Introduction. Beverly Hills: Sage.

Woelfel, J., & Haller, A. O. (1971). Significant others, the self-reflexive act, and the attitude formation process. American Sociological Review, 36, 37-74.

Wohlert, K., & Grant, A. E. (1992, February). The impact of 'groupware' upon communication networks: a preliminary inquiry. Paper presented at the meeting of the Sunbelt XII International Social Networks, San Diego, CA.

Wolfram, S. (1991). Mathematica: A system of doing mathematics by computer [Computer Program]. Champaign, IL: Wolfram Research Inc.

Zeggelink, E. P. H. (1993). Strangers into friends: The evolution of friendship networks using an individual oriented approach. Amsterdam: Thesis Publishers.

Zeggelink, E. P. H. (1994). Dynamics of structure: An object-oriented approach. Social Networks, 16, 295-334.

Table 1

<u>Initial conditions for simulation</u>

	Low interest heterogeneity	High interest heterogeneity
Low resource heterogeneity	300 groups	300 groups
High resource heterogeneity	300 groups	300 groups

Table 2

Mean number of new communication links adopted. The standard deviations are included in parentheses (N=1,200).

	Low interest heterogeneity	High interest heterogeneity	
Low resource heterogeneity	89.57 (28.96)	86.22 (25.30)	87.87 (27.20)
High resource heterogeneity	9.11 (3.84)	11.13 (5.10)	10.12 (4.63)
	48.79 (45.18)	48.62 (41.76)	48.70 (43.47)

Table 3

Resource and interest heterogeneity as predictors of adoption The standard errors are included in parentheses (N=1,200).

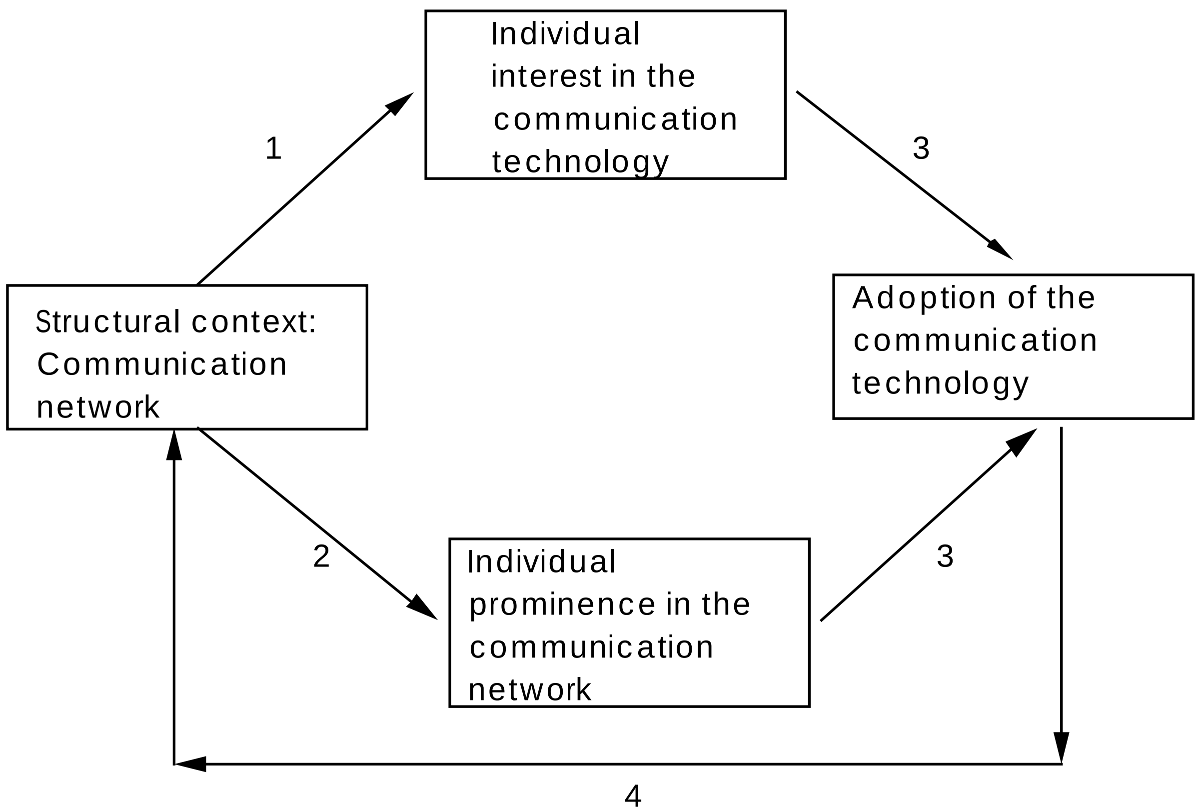
	New links at Time 2	New links at Time 3	New links at Time 4	New links at Time 5	Total new links
Constant	-418.33** (7.95)	-31.99** (2.48)	-11.31** (1.31)	-4.01** (0.74)	-465.65** (7.53)
Resource Heterogeneity	-510.05** (8.52)	-32.12** (2.66)	-11.61** (1.40)	-4.11** (0.80)	-557.89** (8.07)
Interest Heterogeneity	-10.54** (1.55)	7.17** (0.36)	1.82** (0.19)	0.62** (0.11)	0.94 (1.09)
R-squared	0.76	.45	.12	0.14	0.80

* p < .05

** p < 0.01

Figure Captions

Figure 1. Adoption of communication technologies based on Burt's Structural Theory of Action.


Individual interest in the communication technology
1
3
Structural context: Communication network
Adoption of the communication technology
2
3
Individual prominence in the communication network
4