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Social network thresholds in the diffusion of innovations ☆

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Abstract

Threshold models have been postulated as one explanation for the success or failure of collective action and the diffusion of innovations. The present paper creates a social network threshold model of the diffusion of innovations based on the Ryan and Gross (1943) adopter categories: (1) early adopters; (2) early majority; (3) late majority; (4) laggards. This new model uses social networks as a basis for adopter categorization, instead of solely relying on the system-level analysis used previously. The present paper argues that these four adopter categories can be created either with respect to the entire social system, or with respect to an individual's personal network. This dual typology is used to analyze three diffusion datasets to show how external influence and opinion leadership channel the diffusion of innovations. Network thresholds can be used (1) to vary the definition of behavioral contagion, (2) to predict the pattern of diffusion of innovations, and (3) to identify opinion leaders and followers in order to understand the two-step flow hypothesis better.

1. Introduction

Individuals vary in their willingness to take risks in adopting a new idea or product. A few individuals accept the risk of adopting a new idea, product or behavior before anyone else. In contrast, most people are reluctant to adopt a new idea or product and prefer to wait until other people have tried it first. How can researchers determine who will take risks and who will not? How can researchers describe the influence process that occurs between individuals who take risks by adopting an innovation early, and those who do not? The present essay explores

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answers to these questions in the context of the role of social networks in the diffusion of innovations.

The diffusion of innovations is the process by which a few members of a social system initially adopt an innovation, then over time more individuals adopt until all (or most) members adopt the new idea (Ryan and Gross, 1943; Rogers, 1983; Valente, 1993). Recent research on collective behavior has focused on threshold models (Granovetter, 1978; Macy, 1991) and critical mass models (Marwell et al., 1988; Macy, 1990; Oliver et al., 1985; Oliver and Marwell, 1988), and some attempts have been made to apply these models to the diffusion of new communication technologies (Markus, 1987; Rice et al., 1990). The present investigation uses the threshold concept to provide a social network formulation of the diffusion of several different innovations.

How do social networks influence diffusion? A *social network* is the pattern of friendship, advice, communication or support which exists among the members of a social system (Knoke and Kuklinski, 1982; Burt and Minor, 1983; Wellman, 1988; Scott, 1991). The initial network approach to diffusion research was to count the number of times an individual was nominated as a network partner (in order to measure opinion leadership) and to correlate this variable with innovativeness as measured by an individual's time-of-adoption of the innovation under study (Rogers, 1962; Coleman et al., 1966; Becker, 1970; Rogers and Kincaid, 1981). *Opinion leaders* were defined as those individuals with the highest number of nominations, and were theorized to be a significant influence on the rate of adoption.

This approach to studying diffusion networks was replaced by a more structural [1] approach suggested by Granovetter (1973, 1982). Granovetter argued that weak ties (people loosely connected to others in the network) were necessary for diffusion to occur across subgroups within a system. Burt (1980, 1987) presented a third network approach to diffusion by arguing that structural equivalence (the degree of equality in network position) influenced the adoption of innovations. Other personal and social network characteristics which might influence the diffusion of innovations include centrality, density and reciprocity (Rice, 1994; Valente, 1995).

The present research provides a fourth model of diffusion networks that incorporates threshold effects. *Threshold models* of collective behavior postulate that an individual engages in a behavior based on the proportion of people in the social system already engaged in the behavior (Granovetter, 1978). An individual's adoption of a new collective behavior is thus a function of the behavior of others in the group or system. Individuals with low thresholds engage in collective behavior before many others do, while individuals with high thresholds do so only after most of the group has engaged in the collective behavior.

[1] A structural approach, in this context, refers to the social network structure which is determined by the overall pattern of network ties rather than the ties for a particular actor.

The present article measures thresholds with respect to personal networks rather than whole social systems to understand more fully the role of interpersonal influence in adoption behavior. *Personal networks* are the set of direct ties that an individual has within a social system (Wellman, 1988). The personal network conceptualization of thresholds provides a model of diffusion that creates adopter categories based on innovativeness relative to personal networks. The advantages of this approach are that it can be used (1) to determine the critical mass, (2) to predict the pattern of diffusion of innovation, and (3) to identify opinion leaders and followers in order to understand the two-step flow hypothesis better.

The present model deviates from past diffusion models by (1) explicitly including the influence of non-adopters on adopter decisions, (2) linking micro- and macro-level influences in one model, and (3) testing the results against data rather than relying on computer simulation. Although the present paper primarily addresses diffusion behavior, this network threshold model may be applied to other situations such as opinion formation, collective behavior, and the 'tragedy of the commons' (Hardin, 1968).

2. Network thresholds

Threshold models of collective behavior argue that individuals have varying thresholds, which are postulated as one cause for varying times-of-adoption and thus as a cause for the S-shaped rate of adoption (Hägerstrand, 1967; Dozier, 1977; Granovetter, 1978; Schelling, 1978; Granovetter and Soong, 1983, 1986, 1988). Granovetter's threshold model is based on the premise that thresholds are the proportion of adopters in the social system needed for an individual to adopt an innovation.

A collective behavior threshold is the proportion of adopters in a system prior to an individual's adoption. This system-level threshold is appropriate for collective behaviors such as a riot, since individuals' behavior is observable (and thus information is complete). One difficulty with applying the concept of collective behavior threshold to adoption behavior is that individuals may not accurately monitor the adoption behavior of everyone else in the system. This is particularly true for innovations that are not directly observable, such as family planning, recycling of cans or newspapers, and opinions regarding some issue.

A second difficulty with applying the concept of collective behavior applications to the adoption of innovations is that innovations are often uncertain, ambiguous, and risky (Menzel and Katz, 1955; Moscovici, 1976). Perceived uncertainty and risk encourage individuals to turn to others who have had prior experience with the innovation to learn more about it, to find out how much it costs, and to determine how effective it is (Becker, 1970; Cancian, 1979). Thus, *adoption thresholds* should be measured in terms of direct communication network links with others, in contrast to collective behavior thresholds which are measured for the social system to which the individual belongs.

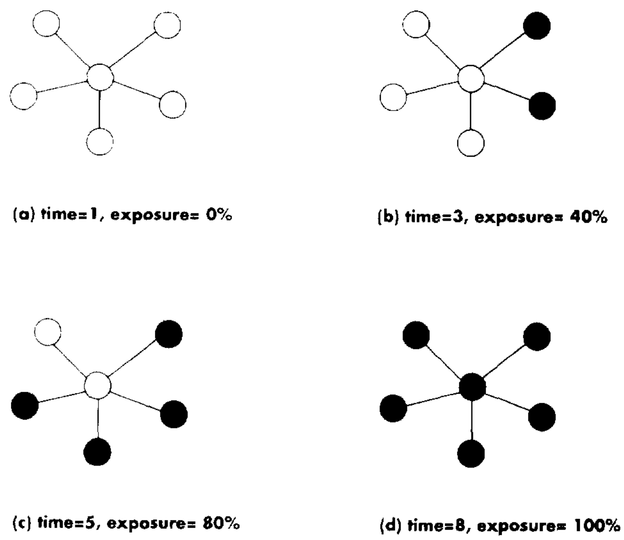

Fig. 1. Personal network exposure to an innovation for a medical doctor. Data are from Coleman et al. (1966). (a) No adopters, exposure is zero. (b) Two partners adopted, exposure is 2/5 or 40%. (c) Two more partners adopted by time period 5, exposure is 4/5 or 80%. (d) All of the individual's personal network partners adopted, exposure is 100%. The threshold is the individual's exposure at time-of-adoption, which is 100% in the present example.

An illustration is provided by Coleman et al. (1966), who collected data on the adoption of a new medical drug (tetracycline) by doctors in four Illinois communities. They also asked each doctor to name three doctors who acted as friendship, advice, and discussion partners. Every doctor had a personal network of from zero to nine other doctors. Fig. 1(a) shows a typical personal network for a doctor (from Peoria, identification number 20) who was connected to five people: two friends, two discussion partners and one advice partner. Fig. 1(b) shows the same personal network 3 months later, when the two discussion partners had adopted tetracycline. Now the individual doctor is exposed to the innovation through his/her personal network partners. The degree of exposure is computed by dividing the number of adopters, 2, by the total size of the personal network, 5. Thus, the degree of exposure to the innovation is 40% for this doctor at time-period 3. In Fig. 1(d), the individual doctor adopts at time-period 8 when all of his/her network partners have adopted. The adoption threshold is the exposure at time-of-adoption. In this example, the doctor adopted tetracycline after all of the other doctors in his/her network adopted, at a threshold of 100%.

The proportion of adopters in an individual's personal network generally increases during the diffusion process, since over time more and more individuals adopt the innovation. This increase in the proportion of adopters in individuals' personal networks does not occur uniformly in a social system, but rather increases according to the structure of the social system, as measured by the patterns of the social network. In other words, everyone's personal network may eventually fill up with adopters, yet some personal networks fill earlier than others, according to the adoption behavior of their network partners.

Exposure is the proportion of adopters in an individual's personal network at a given time. Since adoption thresholds are the proportion of adopters in an individual's personal network, the *threshold* is the exposure at the time-of-adoption. Exposure generally increases over time as more individuals in the social system adopt, and varies across individuals according to the adoption behavior of their network partners.

Prior research (Marsden and Podolny, 1990) argued that network exposure was not related to adoption of innovation (see also Strang, 1990). By constructing an exposure measure similar to that presented here, Marsden and Podolny argued that high exposure did not lead to adoption. This is true precisely because thresholds are crucial to understanding interpersonal influence during diffusion. Exposure may not be related to adoption of innovations because individuals have varying thresholds of adoption. [2]

In sum, individual exposure to an innovation increases as more people in the personal network adopt the innovation. Low network threshold individuals are those who adopt before many others in their network adopt, whereas high network threshold individuals are those who adopt after most of their network have adopted. Note that individuals with the same threshold may adopt at different times since their personal network partners' behavior influences their level of exposure.

Innovativeness (early adoption of innovations) can now be distinguished, i.e. whether individuals are *innovative with respect to their personal network* or *innovative with respect to the social system*. Those with high network thresholds who adopt early relative to the social system are only innovative relative to the social system, not relative to their personal communication network. Low network threshold adopters are individuals who adopt early relative to their personal network yet may (though not necessarily) adopt late relative to the social system.

For example, an engineer working in a software company might buy a personal computer (PC) 4 or 5 years after PCs are introduced into the market. This engineer would be considered an early adopter of PCs. However, this same engineer is probably surrounded by colleagues and friends who adopted PCs when they were first available and thus are earlier adopters of PCs. The engineer who adopted in year four was a late adopter in *his / her personal network*. Many individuals who adopted PCs in year ten or eleven may have known one or two engineers, and thus had some interpersonal exposure to PCs, but they were probably early in their network to adopt even though they had relatively average adoption time *relative to the whole society*.

[2] Event history analysis (Tuma and Hannan, 1984) was conducted on the datasets reported later in this article which also showed that exposure was not related to adoption of innovations.

3. Adopter categories

A major contribution to diffusion research has been the categorization of adopters based on innovativeness as measured by time-of-adoption (Rogers, 1958). Adopters are classified as (1) early adopters, (2) early majority, (3) late majority, and (4) laggards (Ryan and Gross, 1943, 1950; Beal and Bohlen, 1955; Rogers, 1983, pp. 245–247). [3] *Early adopters* are individuals whose time-of-adoption is greater than one standard deviation earlier than the average time-of-adoption. The *early and late majorities* are individuals whose time-of-adoption is bounded by one standard deviation earlier and later than the average. Finally, *laggards* are those individuals who adopted later than one standard deviation from the mean.

Personal network threshold adopter categories may be created by partitioning the network threshold distribution in the same manner described for time-of-adoption adopter categories. Specifically, *very low network threshold* individuals have personal network thresholds one standard deviation lower than the average threshold. *Low and high network threshold* individuals have personal network thresholds bounded by one standard deviation less than and greater than average. Finally, *very high network threshold* individuals have personal network thresholds one standard deviation greater than average. The average threshold being the mean threshold for the community.

Adopter categories provide a mechanism for audience segmentation, the comparison of research results, and the summation of research findings (Rogers, 1983). Specifically, adopter categories were created to compare early adopters with later adopters to determine differences in their social and personal characteristics, communication behavior, and opinion leadership. One of the primary research findings of diffusion research was that early adopters had more sources of external influence.

4. External influence

Two possible external sources of influence on adoption of innovations are cosmopolitan [4] actions and communication media. Cosmopolitan actions and media consumption provide individuals with earlier awareness of an innovation (Becker, 1970; Fischer, 1978; Weimann, 1982) and freedom from system norms (Menzel, 1960), enabling them to be earlier adopters and proponents of an innovation. In communities such as art and science, the norm is for innovative behavior and so external influence may operate differently (Michaelson, 1993).

[3] Rogers' (1993) classification includes *innovators* who are individuals who adopt extremely early. Innovators are interesting in that they are the very first to adopt, but here are included with early adopters since they represent a small fraction of the sample (2.5%).

[4] A *cosmopolitan* individual is oriented to the world outside of his/her local social system (Merton, 1968) and relates his/her local social system to the larger environment by providing links to outside information (Gouldner, 1957, 1958; Davis, 1961).

Table 1
Three datasets, re-analyzed in the present paper, which collected data on time-of-adoption and social networks

	Medical innovation	Brazilian farmers	Korean family planning
Country	USA	Brazil	Korea
Number of respondents	125 doctors	692 farmers	1047 women
Number of communities	4	11	25
Innovation	Tetracycline	Hybrid corn	Family planning
Length of time for diffusion	18 months	20 years	11 years
Year data collected	1955	1966	1973
Average time of 50% adoption	6 months	16 years	7 years
Lowest saturation	81%	29%	44%
Highest saturation	89%	98%	83%
Source of adoption data	Prescription records	Respondent recall	Respondent recall
Network nominations mean (s.d.)	2.35, (1.3)	2.63, (1.61)	4.02, (2.60)
External influence, mean (s.d.)	Medical journals 4.11, (1.97)	City visits 6.33, (12.70)	Campaign score 12.22, (7.59)
Reference	Coleman et al. (1966)	Rogers et al. (1970)	Rogers and Kincaid (1981)

The thesis tested here is that the role of external influence on adoption of innovations is clarified when one considers thresholds relative to the social system and personal networks. Furthermore, this dual classification permits specification of how external and interpersonal influence flow through the system and govern the diffusion of innovations.

5. Empirical analyses

Empirical analysis of the personal network threshold model requires data collected on (1) time-of-adoption and (2) social network ties. Three datasets meet these requirements: (1) the medical innovation diffusion study by Coleman et al. (1966; see also Burt, 1987); (2) the study of Brazilian farmers' adoption of hybrid seed corn (Herzog et al., 1968; Rogers et al., 1970; Guimarães, 1972); (3) the Korean family planning study by Rogers and Kincaid (1981; see also Dozier, 1977; Lee, 1977; Granovetter, 1978). The characteristics of these datasets are summarized in Table 1. [5]

[5] Two other studies, one by Becker (1970) and one by Rogers (1965), collected both time of adoption and network data, but the data are no longer available.

5.1. Medical innovation study

The medical innovation data were collected in the mid-1950s in four Illinois communities: Bloomington, Galesburg, Peoria, and Quincy. The respondents were 125 physicians who could have prescribed a new drug, tetracycline (referred to as 'gammanym' in the original study). Social network data were collected by asking doctors in the four communities to name three doctors from whom they most frequently sought (1) discussion, (2) friendship, and (3) advice.

Adoption data were collected by examining drug prescription records at local pharmacies to determine when the doctors in the four communities first prescribed tetracycline. The data were collected over an 18-month period, by which time over 80% of the doctors in each community had prescribed tetracycline at least once. The data were collected by sampling prescription records during three consecutive days, every 28 days [6].

Diffusion occurred quickly in the medical innovation study: by month six, at least half of all doctors had prescribed tetracycline at least once. The central conclusion of the Coleman et al. (1966) study was that diffusion occurred more quickly among those doctors most integrated into the social system. For example, diffusion occurred fastest among doctors who received four or more network nominations as advisors. Coleman et al. (1966) also asked doctors how many medical journals they subscribed to, and this measure is the external influence variable examined in the present re-analysis.

5.2. Brazilian farmers

In 1966 a study of the diffusion of hybrid corn among 692 farmers in 11 Brazilian villages was conducted. The year in which farmers recalled having first planted hybrid corn was the time-of-adoption [7]. Network data were collected by asking farmers to name (1) their three best friends, (2) the three most influential people in their community, (3) the three most influential people regarding various farm innovations, and (4) the best person to organize a cooperative project.

The time-of-adoption data were based on respondents' recall, which might be subject to error (Coughenour, 1965). It can be argued that farmers' purchase of hybrid corn is a radical event, fundamentally changing their livelihood, thus increasing the likelihood of accurate recall. Some respondents stated adoption times as much as 15 years prior to the interview, and while these data are potentially accurate, recall of such a distant event may be erroneous. It is hoped that recall errors are normally distributed. The Brazilian farmer data measured

[6] This sampling strategy creates some error in the time-of-adoption data which might give some individuals later adoption times than were actually the case.

[7] Hybrid corn was first available in corn-belt states in the US in the 1930s, and diffused throughout the US in the 1940s and 1950s. It spread globally in the late 1940s and throughout the 1950s, with widespread adoption occurring in the 1960s (Crabb, 1948; Wallace and Brown, 1988).

cosmopolitan external influence by the number of visits to the nearest large city within the past month.

5.3. The Korean family planning study

Scholars at Seoul National University's School of Public Health collected data on the adoption of family planning methods among all married women of child-bearing age in 25 Korean villages in 1973 ($N = 1047$). Network data were obtained by asking the women to name five people from whom they sought advice about (1) family planning, (2) general information, (3) abortion, (4) health, (5) the purchase of consumer goods, and (6) children's education.

Time-of-adoption data were obtained by asking respondents to state the year in which they first used a modern family planning method. Again, this recall data may be subject to some error. Conversely, family planning is a highly salient practice to Korean married women, and it is likely that they would remember when they started such a practice (Nischan et al., 1993). The external influence variable used in the present re-analysis is a respondents' media campaign exposure, with higher scores indicating greater exposure to the national family planning campaign [8].

5.4. Results

Table 2 shows the cell percentages for the adopter categories relative to the system and relative to personal networks for all three datasets. These two variables are associated with one another (X^2, $p < 0.001$) for all three datasets. This is not surprising given that one's time-of-adoption is associated with the proportion of adopters in the social system, and thus associated with the proportion in any individual's personal network.

Forty-three percent of the doctors in the medical innovation study were classified identically in both their social system and personal network thresholds. For the Brazilian farmers 47% were classified the same, while 64% of the Korean women were classified the same. The proportion not classified similarly are in the off-diagonal cells and represent individuals who are more innovative relative to the system than to their network (the upper triangle in Table 2) or more innovative relative to their personal network than the system (lower triangle). For example, in row 1 column 2, 4.8% of the doctors are more innovative relative to the system since they adopted in the early adopter phase, yet waited until some portion of their personal network adopted.

All the Brazilian farmers in the laggard phase have either very low or very high thresholds (row 11, columns 2 and 3). This is also true for the Korean women (row 12, columns 2 and 3), with the additional provision that there are no women with

[8] Respondents were asked to name how often (on a four-point scale) they were exposed to the campaign for 14 media, such as television, radio, posters, etc. This total score was then divided by an index of media ownership.

Table 2
Proportions for adopter categories based on innovativeness relative to social system and innovativeness relative to personal networks

	Personal network: direct ties				System total
	Very low threshold	Low threshold	High threshold	Very high threshold	
Early adopters					
Doctors	**9.6**	4.8	1.6	–	16.0
Farmers	**12.9**	6.9	1.9	1.9	23.5
Women	**12.7**	8.0	2.6	–	23.3
Early majority					
Doctors	12.0	**12.8**	8.0	11.2	44.0
Farmers	4.5	**6.9**	1.2	2.7	15.3
Women	4.0	**10.5**	10.9	–	25.4
Late majority					
Doctors	4.8	0.8	**2.4**	10.4	18.4
Farmers	5.5	6.6	**8.8**	18.2	39.2
Women	2.3	5.2	**8.1**	–	35.7
Laggards					
Doctors	1.6	0.8	0.8	**18.4**	21.6
Farmers	3.6	–	–	**18.3**	22.0
Women	3.1	–	–	**32.6**	35.7
Personal network total					
Doctors	28.0	19.2	12.8	40.0	100
Farmers	26.4	20.5	11.8	41.2	100
Women	22.2	23.7	21.6	32.6	100

Note: Variables in all three datasets are significantly associated with one another, χ^2, $p < 0.001$.

very high thresholds who are adopters (rows 3, 6 and 9, column 4). These empty cells represent skewness in the data that arises from considerable proportions of nonadopters in the respective datasets: 22% for the Brazilian farmers, and 32.6% for the Korean women. The reason for this skewness is that the respective innovations have not finished diffusing.

Table 3 reports the external influence scores for each of the 16 categories of adopters for the three datasets. This table shows how external influence scores vary for individuals who are innovative relative to the two dimensions. For example, doctors who are most innovative relative to the social system *and* have very low thresholds (row 1, column 1) subscribed to an average 5.17 of medical journals. Farmers in this category made an average of 12.11 visits to the nearest large city in the past year, and Korean women scored 12.69 on the family planning campaign exposure scale.

Doctors who were early adopters relative to the system and had low thresholds subscribed to an average of 4.17 medical journals (row 1, column 2). Farmers in

Table 3
External influence (journal subscriptions, city visits, campaign exposure) by system and cohesion network thresholds

	Personal network: direct ties				System total
	Very low threshold	Low threshold	High threshold	Very high threshold	
Early adopters					
Journals [a]	**5.17**	4.17	4.50	–	4.80
Visits [b]	**12.11**	7.83	2.54	3.08	9.35
Campaign [c]	**12.69**	15.06	13.66	–	13.62
Early majority					
Journals	3.33	**5.06**	4.50	4.21	4.27
Visits	10.81	**8.00**	2.25	4.79	7.81
Campaign	8.14	**14.22**	13.55	–	12.98
Late majority					
Journals	3.83	8.00	**4.00**	4.00	4.13
Visits	4.16	3.80	**4.92**	3.88	4.14
Campaign	11.02	13.67	**14.32**	–	13.67
Laggards					
Journals	3.50	2.00	2.00	**3.35**	3.26
Visits	1.96	–	–	**6.78**	5.98
Campaign	6.76	–	–	**10.29**	10.03
Personal network total					
Journals	4.06	4.83	4.25	3.76	4.11
Visits	8.84	6.58	4.27	5.19	6.33
Campaign	6.97	8.94	8.36	5.92	12.22

[a] ANOVA main and interaction term associations are non-significant.
[b] ANOVA main and interaction term associations are significant at $p < 0.05$.
[c] ANOVA main effects association is significant at $p < 0.001$ and interaction term is non-significant.

this category made an average of 7.83 visits to the nearest large city in the previous year, and Korean women scored 15.06 on the family planning campaign exposure scale (higher scores indicate higher exposure).

Analysis of variance was conducted to test the association between the innovativeness variables and the degree of external influence. The ANOVA results were not consistent across datasets, indicating that external influence may have operated differently in the three studies. For example, doctors' medical journal subscriptions were not associated with either innovativeness dimensions, whereas farmers' visits to the city were associated with both innovativeness dimensions and the interaction term (see Table 3).

Table 3 shows that external influence scores are almost always highest for individuals who are most innovative relative to the system *and* their personal network. These are the earliest adopters (innovators), who are the first to adopt the innovation. Their early adoption is associated with high external influence.

Second, the upper-triangle scores in Table 3 are usually greater than the respective lower-triangle scores, indicating that external influence tends to make individuals innovative relative to the social system more than relative to their personal network.

Third, one would expect that within diffusion phases the external influence scores would be monotonic by innovativeness relative to network. In other words, if system and personal network influences acted serially, the scores would be greatest for early adopters relative to the system, next for early majority adopters, etc., which is indeed the case. However, within each phase one would expect that very low thresholds would have the highest external influence score, followed by low thresholds, followed by high thresholds, and finally very high thresholds. This is not the case. In fact, generally the diagonal element has the largest or second largest external influence score. This indicates that individuals who are consistent in their innovativeness (at both macro- and micro-levels) tend to have the highest external influence in their adoption phase.

Fourth, laggards (those who never adopt or adopt late) can be partitioned into isolates and high thresholds. Laggards who have very low thresholds do not receive exposure to the innovation from their network, and (according to Table 3) are not being exposed to the innovation through external influence. It is unclear whether these isolates will ever adopt, since there seems to be no mechanism for them to learn about the innovation.

Conversely, high network threshold laggards hear about the innovation, but do not adopt. Thus, the latest adopters can be partitioned into those who did not adopt because they did not hear about the innovation (rows 10–12, column 1), and those who did not adopt because of resistance (rows 10–12, column 4).

As mentioned above, although external influences are generally responsible for making individuals aware of innovations, it is often interpersonal influence with friends and neighbors which lead to actual adoption. The long-standing theory of diffusion has been that the media, salesmen, campaigns, targeted literature, and other factors make individuals aware of innovations, but interpersonal persuasion is necessary to convince individuals to adopt (Ryan and Gross, 1943; Rogers, 1983). Thus, the two-step flow hypothesis was created (Katz, 1957; Weimann, 1982), which stated that the media inform opinion leaders who, in a second step, influence opinion followers.

Social network thresholds permit specification of this two-step flow by postulating that opinion leaders are those individuals with lower thresholds who influence those with higher thresholds to adopt. Thus, innovativeness relative to one's personal network should be associated with opinion leadership. *Opinion leadership* is measured by the number of network nominations received (Rogers and Cartano, 1962). In fact, the pattern of network nominations received for the 16 categories of adopters indicates the flow of interpersonal influence.

Table 4 shows the average number of network nominations received for the 16 categories for the three datasets. The highest scores generally occur along the diagonal of Table 4. Individuals who adopt when their system and network level exposure are about the same are more likely to be opinion leaders. Thus, opinion

Table 4
Opinion leadership scores (number of network nominations received) by system and cohesion network categories

	Personal network: direct ties				System total
	Very low threshold	Low threshold	High threshold	Very high threshold	
Early adopters					
Doctors [a]	**3.08**	2.00	1.50	–	2.60
Farmers [b]	**3.07**	1.77	4.38	3.23	2.80
Women [c]	**5.47**	5.24	5.04	–	5.34
Early majority					
Doctors	1.27	**4.31**	3.50	2.29	2.82
Farmers	3.45	**3.94**	8.00	2.47	3.84
Women	3.05	**4.86**	4.69	–	4.50
Late majority					
Doctors	1.00	2.00	**5.33**	2.23	2.30
Farmers	2.84	2.91	**2.87**	2.71	2.80
Women	2.38	3.69	**3.91**	–	3.61
Laggards					
Doctors	0.50	0.00	2.00	**1.35**	1.26
Farmers	0.40	–	–	**1.48**	1.30
Women	1.36	–	–	**3.15**	2.99
Personal network total					
Doctors	1.80	3.46	3.50	1.84	2.35
Farmers	2.72	2.87	3.61	2.17	2.63
Women	4.13	4.73	4.44	3.15	4.02

[a] ANOVA diffusion phase significant at $p < 0.05$.
[b] ANOVA network threshold significant at $p < 0.01$.
[c] ANOVA both main effects significant at $p < 0.001$.

leaders behave in a normative fashion by having consistency in their system and personal network thresholds.

For early adopters, it is normative for them to adopt early relative to their personal network, and these individuals are more likely to be opinion leaders. For example, doctors who adopt early relative to both system and network (row 1, column 1) receive an average of 3.08 nominations. Early adopter doctors (system-level) with low thresholds (row 1, column 2) receive an average of 2.0 network nominations, compared with early adopter doctors who have high thresholds and who receive only 1.5 network nominations. For early majority doctors, row 4, those with low thresholds have the highest number of network nominations received: 4.31.

Individuals who exhibit consistency in their threshold are appropriate role models and near peers whose behavior may be imitated. Individuals who are more innovative relative to their network for that phase of diffusion are generally not appropriate role models for others at that stage. These individuals deviate from the norm for that stage of diffusion, and hence cannot act as role models for others.

Second, the pattern of nominations received is different for the three datasets. The opinion leadership scores increase along the diagonal for the medical innovation data, but show several inconsistencies for the Brazilian farmers, and decrease along the diagonal for the Korean women. This may indicate that the flow of interpersonal influence was different in the three studies.

As Coleman et al. (1966) showed, innovation in the medical community was usually associated with network integration. In other words, diffusion occurred via contagion, like a snowball process, in which doctors who were connected to each other influenced one another through their ties within the social system. This is generally true, and within each diffusion phase doctors who are consistent relative to the system and their personal network are the opinion leaders.

However, the earliest adopters relative to the system may be oriented to the larger medical community, perhaps in Chicago or New York (as also evidenced by their medical journal subscriptions). Consequently, these early adopter doctors do not receive the most nominations within the system, and their opinion leadership scores are depressed by their external system contact [9].

In contrast, the Brazilian data contains inconsistencies in the distribution of opinion leadership scores. Within some diffusion phases, opinion leadership scores are highest for farmers in off-diagonal cells (see Table 4). For example, in the early adopter phase, farmers who adopted with high network thresholds had the greatest number of network nominations received (this may be a result of the small percentage who fall into this category, see Table 2). Consequently, interpersonal influence may not have flowed through the Brazilian farmer networks in a discernable pattern.

For the Korean data, opinion leadership seemed to follow the classic diffusion model. That is, opinion leader scores are highest along the diagonal in Table 4, indicating that individuals who were consistent in their thresholds were more likely to be opinion leaders. Moreover, network nominations received are highest for women who adopted earliest. That is, early adopters relative to system *and* personal network received the most network nominations for that phase of diffusion, and received the most nominations overall (5.47 nominations, row 3, column 1). Women with system and network thresholds in the early majority category received the second highest opinion leadership scores (4.86 nominations), and late majority women received the third highest opinion leadership scores (3.91).

[9] A second reason for the lower opinion leadership scores of the earlier adopters is the inherent conservatism of the medical community. As mentioned throughout the Coleman et al. (1996) and Burt (1987) analyses, doctors must turn to others for advice and reassurance concerning the adoption of new therapies. The risk and uncertainty associated with innovation forces doctors to wait until a sufficient number of other doctors in the system adopt.

Opinion leadership by earlier adopters indicates that the flow of interpersonal influence was perhaps contained within the social system of Korean women. That is, the early adopters of family planning became opinion leaders in their communities and may have disseminated information and influence about family planning to other members of their village. The later adopters turned to these earlier adopters, perhaps to get more information or reassurance about modern family planning methods. These later adopters would then adopt, but the earliest adopters would still remain the opinion leaders in the village.

Innovativeness may have contributed to the opinion leadership of the Korean women. The Korean women who adopted early became opinion leaders, perhaps in part due to their early adoption of innovations. In contrast, the medical doctors' opinion structure did not change as a result of adoption behavior. To be sure, doctors who had low network thresholds were considered opinion leaders in their phase of diffusion, but early adoption of tetracycline did not increase the likelihood that a doctor would be considered an opinion leader in the community.

Fig. 2 illustrates the difference in opinion leadership scores for the medical innovation and Korean data by graphing the number of network nominations received for adopters in each diffusion phase by their threshold category. This shows that for each diffusion phase the number of network nominations received was highest for doctors who adopted with the corresponding network threshold category. For example, early adopter doctors received the most network nominations if they adopted with very low thresholds, and early majority doctors received the most nominations if they adopted with low thresholds. In contrast, for the Korean women, the number of nominations received was highest for the earliest adopters, regardless of threshold status, and progressively decreased during diffusion for all network threshold categories.

Why are these two opinion processes different? In other words, why is innovativeness associated with opinion leadership for Korean women and not for Illinois medical doctors? The medical community is an extremely hierarchical social system in which standards of perceived excellence, such as medical school attended, sophistication of clients, etc., are known by other doctors. In contrast, rural Korean women in the 1960s and early 1970s probably based social status, and hence perhaps opinion leadership, on the degree of modernity, wealth, and formal education, all of which are associated with the adoption of modern family planning practices.

In sum, it seems that the diffusion of innovations in these three datasets followed three different patterns, perhaps as the result of three different influence processes. For the medical innovation data, doctors connected to the broader medical community in Chicago or New York may have been the first to adopt and became opinion leaders for their phase of diffusion. Subsequent adoption was probably based on opinion leadership within stages of diffusion. Thus, the medical innovation data support the two-step flow model in which external influence leads to opinion leadership within phases of diffusion, but not across phases.

For Brazilian farmers, cosmopolitan contact, as measured by visits to the nearest city, had the strongest influence on the adoption of hybrid corn, and

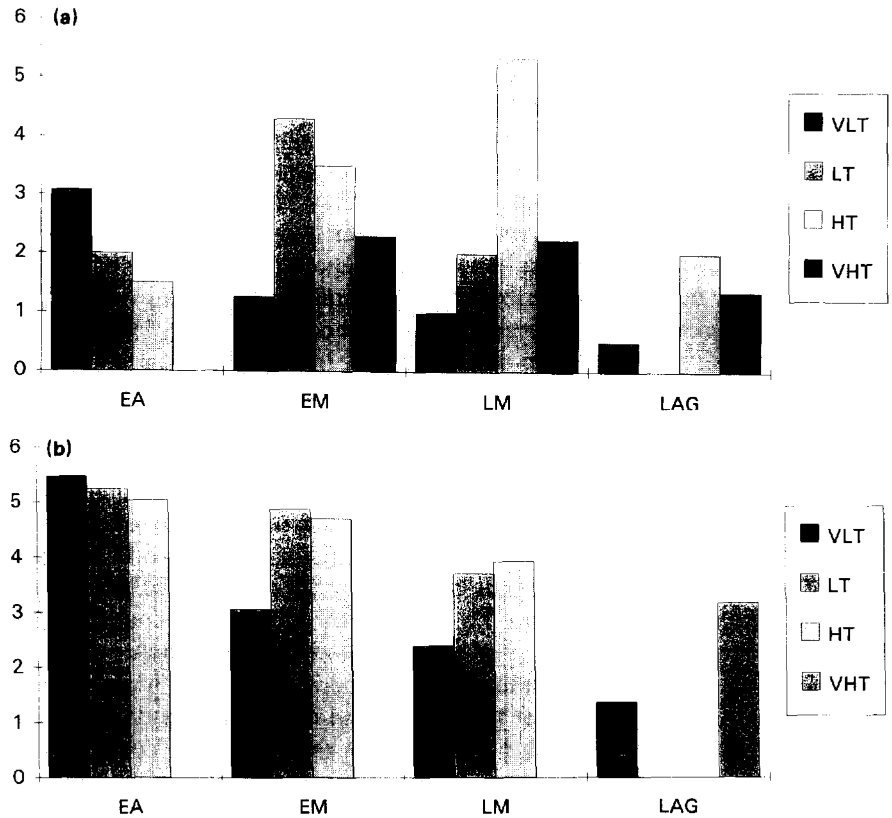

Fig. 2. (a) Medical doctor opinion leadership scores measured as the number of network nominations received by diffusion stage (EA, early adopter; EM, early majority; LM, late majority; LAG, laggards) and social network threshold VLT, very low threshold; LT, low threshold; HT, high threshold; VHT, very high threshold). (b) Korean women's opinion leadership scores measured as the number of network nominations received by diffusion stage and social network threshold.

interpersonal influence within villages seemed to be less structured. Thus, for Brazilian farmers it may be that being cosmopolitan was associated with earlier adoption, but was not associated with opinion leadership.

For Korean women the classic two-step flow model seemed to operate, in which consistency between system network thresholds was associated with opinion leadership. This opinion leadership was also associated with external influence from the family planning media campaign. Finally, the earliest adopters were considered opinion leaders for the entire village, not just individuals who adopted in their same stage of diffusion.

6. Discussion

Network thresholds are biased by the presence of time lags between the time an individual's exposure reaches his/her threshold and his/her time-of-adoption.

Threshold lags occur because individuals are not immediately influenced by their peers, but may continually monitor their peers' behavior. The magnitude of the threshold lags indicates the degree of delay in threshold activation. For example, an individual may have an exposure value of 60% at time period 3, but then wait for five time periods before adopting without any change in the adoption of his/her personal network. This individual would have a lag of five time periods [10].

A second difficulty with network thresholds is a possible bias in the data. The time-of-adoption data reported for these studies is not normally distributed, partly due to the fact that not all respondents had adopted the innovation by the time of data collection. Thus, using the standard deviation to create adopter categories may be misleading. However, adopter categorization based on time-of-adoption is a conventional procedure in diffusion research.

The present approach assumed behavioral contagion through direct network ties. It can easily be extended to other forms of contagion by using other network properties as exposure weights (Karlsson, 1958). Specifically, the present research used direct ties to create exposure scores, but one can also use structural equivalence to model positional influences (Burt, 1987), the flow matrix (which measures the maximum amount of information that can pass from one individual to another through the network; Freeman et al., 1991), and centrality (Bonacich, 1987), as well as two- and three-step connections.

A second direction for threshold research would be to study how thresholds affect pluralistic ignorance (O'Gorman and Garry, 1976) and the spiral of silence (Taylor, 1982; Noelle-Neumann, 1984), which argue that perceptions about majority and minority opinions, whether objectively correct or not, influence individuals' behavior. However, perceptions about minority and majority opinions are shaped by an individual's personal network, and thus the network model provides one means to study these opinion influences.

The social network threshold concept introduces the possibility of varying individuals' frames of reference. Over 50 years of diffusion research has treated time-of-adoption with respect to the whole social system as the key dependent variable to be predicted (Valente and Rogers, 1995) while ignoring how individuals act with respect to their personal network (however defined). Attempts to demonstrate contagion have been frustrated by results which show that network exposure does not necessarily lead to adoption (Valente, 1995).

Contagion can still be proven by accounting for individual threshold differences. Both diffusion and network theory will benefit from understanding the micro-process of behavioral contagion. It may be that social network thresholds provide the means to determine which type of network influences lead to innovation adoption.

[10] Empirical analysis on the present datasets showed that exposure to media sources (Brazilian farmers) and a media campaign (Korean family planning) resulted in lower threshold lags. This result persisted when controlling for time-of-adoption.

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