The Generation and Diffusion of Managerial Innovations: A System Dynamics Model

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Abstract

This paper presents a model that attempts to examine what happens when an innovation takes a less tangible form, such as a managerial method. Because it is more difficult to track the adoption or measure the benefits of such innovations, organizations often fail to use valuable knowledge when attempting to solve difficult problems. Existing research suggests that intangible managerial innovations are more likely to be adopted if a group of adherents develops to support and foster innovation. This research investigates the role that these groups, often called "invisible colleges" play in this transfer of knowledge. A preliminary system-type model, based on the existing literature is presented and discussed.

Introduction

Research on the diffusion of innovation has tended to focus on time patterns reflecting to the adoption of tangible products (Rogers, 1983), such as hybrid corn seed (Ryan and Gross, 1943). Intangible innovations, such as new processes for the manufacture of steel (Oster, 1982) are generally tracked through the purchase history of the machinery needed to implement the new process. Existing models of diffusion, which essentially eliminate feedback effects, are useful for those interested in the speed and extent of product adoption. However, they are less useful in explaining the underlying processes, or explaining the reoccurring nature of innovation. This omission is especially relevant with respect to intangible managerial innovations, because the social system underlying the diffusion process is more relevant to the adoption of ideas.

Intangible innovations are more likely to be adopted if groups of adherents develop to foster and support them (Crane, 1972; Price, 1963). Thus, the dynamics of group formation are more important than the time trace associated with the diffusion process. System dynamics models offer distinct advantages because they incorporate the feedback effects that determine how knowledge growth, support groups, funding, publications, and the existing inventory of problems affects the diffusion process and the rate at which the stock of knowledge grows.

In this paper, such a model is developed. The patterns (time-traces) and speeds of diffusion for intangible intellectual innovations and the detailed nature of the process by which intellectual innovations move between and within academic and applied settings is discussed. The systematic ways that "invisible colleges" affect these various forms of diffusion is also discussed. Factors that affect the transfer, and external interventions that affect the use, of intangible managerial innovations are specifically incorporated into the model. The model is exploited to suggest a series of research propositions, which are discussed in terms of their organizational implications.

Background

The notion that informal organizations might play an important role in the spread of knowledge was first mentioned in 1646 by the chemist Robert Boyle, in reference to a group of scholars exchanging information and ideas outside the confines of more visible colleges (Birch,

1756). Referred to as "invisible colleges," the existence of these organizations was used to help explain how particular research questions gained status, and the development, around them of restricted, yet efficient, communication networks (Crane, 1972; Price, 1963).

In the social and behavioral sciences geographic space (Brown, 1981), the availability of support funds (Wassenberg, 1977), the presence of social support networks (Ryan and Gross, 1943), and the visibility of research consequences (Dutton and Starbuck, 1979) have been found to be important factors in the diffusion of intellectual technologies. This is because innovative ideas must move through the same temporal and spatial dimensions, as tangible products, but without the propagator and nonpropagator agencies that facilitate the diffusion of more visible innovations. Opinion leaders and activities bringing together those sharing similar interests provide a means to use, or develop, social networks to foster the spread of these intellectual innovations.

Thus, this external intervention by opinion leaders provides needed initial support for a research paradigm, because a visible group of adherents is required to initiate acceptance of new ideas, especially where an established accepted theory already exists that preserves prior notions (Kuhn, 1962). These adherents form informal networks capable of either facilitating or suppressing the growth and spread of knowledge. But as with the s-shaped curve, normally associated with diffusion, our understanding knowledge of the underlying role of these "invisible colleges"in this process is incomplete. This is especially true with respect to the role they play in knowledge generation.

The process by which diffusion occurs and organizations learn, especially with respect to new technologies, can be viewed as both an external and internal process (Hedberg, 1981). This suggests that a systems approach may be needed to appreciate the relationship between the different factors, both internal and external that are relevant. Research on networks supports the notion that a more complex model is needed to explain this process (Alba, 1982). Thus, it becomes important to consider the role that "invisible colleges" may play in this process, While accounting for other factors affecting the diffusion process. Crane (1972) suggested that the absence of an "invisible college" might result in a linear diffusion curve for an intangible innovation, which would be much slower than diffusion characterized by the traditional s-shaped curve.

Communication theoretic research, in addition to being concerned with networks and "opinion leaders," has also been concerned with the spread of ideas (Becker, 1970) and geographers have long recognized the impact of physical barriers and distance on the movement of ideas (Baranson, 1966). Torsten Hagerstrand (1952, 1953), a renowned Swedish geographer, discovered that neighborhood effects and physical distance play an important role in explaining paths of adoption. As Brown (1981) pointed out, conditions related to supply and demand produce the dynamic and profit-seeking behavior needed for the diffusion of product innovations. For intangible innovations, convention meetings, academic publications, interactions with members of the applied community, and mobility play roles in overcoming neighborhood effects and help explain how knowledge gets communicated.

Thus, as developed in the literature, the concept of an "invisible college" suggests that these informal organizations serve as important substitutes for the propagator and non-propagator agencies that support the diffusion of tangible innovations. They also serve as supplements to the more stable knowledge based institutions, such as universities, that exist in society. Studying diffusion of knowledge, Crane (1972) found that as more researchers became interested in a field of study, membership in an "invisible college" grew. She also found new ideas could be characterized by adaptive growth, where periods of slow growth were respectively followed by periods of exponential, linear, and minimal growth. When an idea or area originates, few researchers work in the field. But gradually, as evidenced by the rapid increases in rates of publication, belief in the importance of a new research area occurs. Eventually, publication rates level off, as the more obvious problems in the area have been addressed. Crane believed "invisible colleges' played an important role and helped account for these growth phases because they created the interfaces, and provided the impetus needed, to create interest in the area.

Price (1963) suggested the costs of growth may eventually lead to long run decline because the level of knowledge gained for investigating a circumscribed range of problems, in any field, begins to yield diminishing returns. In research, this can account for increased costs of discovery

and to declines in productivity (Ben-David, 1971). To offset a decline in scientific productivity, researchers shift their attention from mature to less mature fields. A new field that receives these "in-migrants" may benefit from the research techniques they bring from their former areas. From an economic perspective, decline occurs as researchers see "pay-offs" decreasing and move to another area where the rewards are greater.

For such switching to occur, not only must new problem area compete with existing ones, but different disciplines must offer competing perspectives. Thus, scientific productivity, in a broader sense, may itself depend on the number of such differentiated disciplines as they promote hybridization across fields and the birth of new areas of inquiry.

Generation and Diffusion Model

The dynamic nature of the knowledge generation and diffusion process, together with the relevant parameters and variables involved in the spread of an intangible innovation, are depicted in Figure 1. This model is best conceptualized as consisting of four interrelated sub-sectors. Each sub-sector attempts to relate a set of factors to a more central variable, thus helping to explain the dynamics of the innovation generation, diffusion and adoption process. These central foci are the (1) size or membership of the "invisible college," (2) number of geographical locations or work sites, (3) size of the readership pool, and (4) size of the current inventory of unsolved problems. The relationship for each of these area is posited to have both antecedent and precedent factors.

The number of active researchers in the problem area defines the size of the "invisible college." Readership plays an important role in this process because it serves as one of the vehicles that attracts other researchers and students to the problem area. There is some evidence to suggest that size is directly affect by the failure of current researchers to recruit new members (Fisher, 1966), although this function would seem more important in the earlier stages of an innovation's life. Thus, the desire to reach a readership that is interested in the subject, the optic being used to view the subject, or the method of analysis, becomes important to the the current members. The nature of the membership factor suggests the following dynamics.

> Proposition 1. Membership in an "invisible college" is positively related to the size of the current membership pool.
>
> Proposition 2. The number of work sites has a direct impact on the growth of membership.
>
> Proposition 3. The membership pool, while generating , which also appears to facilitate the movement of members, some current members move to other research areas.

Research thus acts as a spur to membership. As researchers become familiar with the literature of a problem area, they may be encouraged to do research in the area and thus join the "invisible college." The informal links between the members of a college will develop gradually, and may first occur between members at the same work site or at academic conventions. Work sites also act positively to affect membership through this communication link. Colleagues share ideas, and this encourages others to work in the same problem area (Smith, 1989). Particular research questions may also develop prominence at a particular work site, which acts to encourage junior faculty and doctoral students to examine the area for interesting research ideas. The absolute number of work sites should also have a positive impact because, as this number grows, researchers at nonrepresented sites may be encouraged to join.

The movement of researchers across sites also influences membership. As more niches of opportunity and status get filled, some members may migrate to other sites in search of recognition and status, as more permanent establishments such as universities strive to have representatives in what they see as important areas. Members may also move to new sites due to their commitment to a particular mode of research (Crane, 1972). Movement can also have negative effects because, in

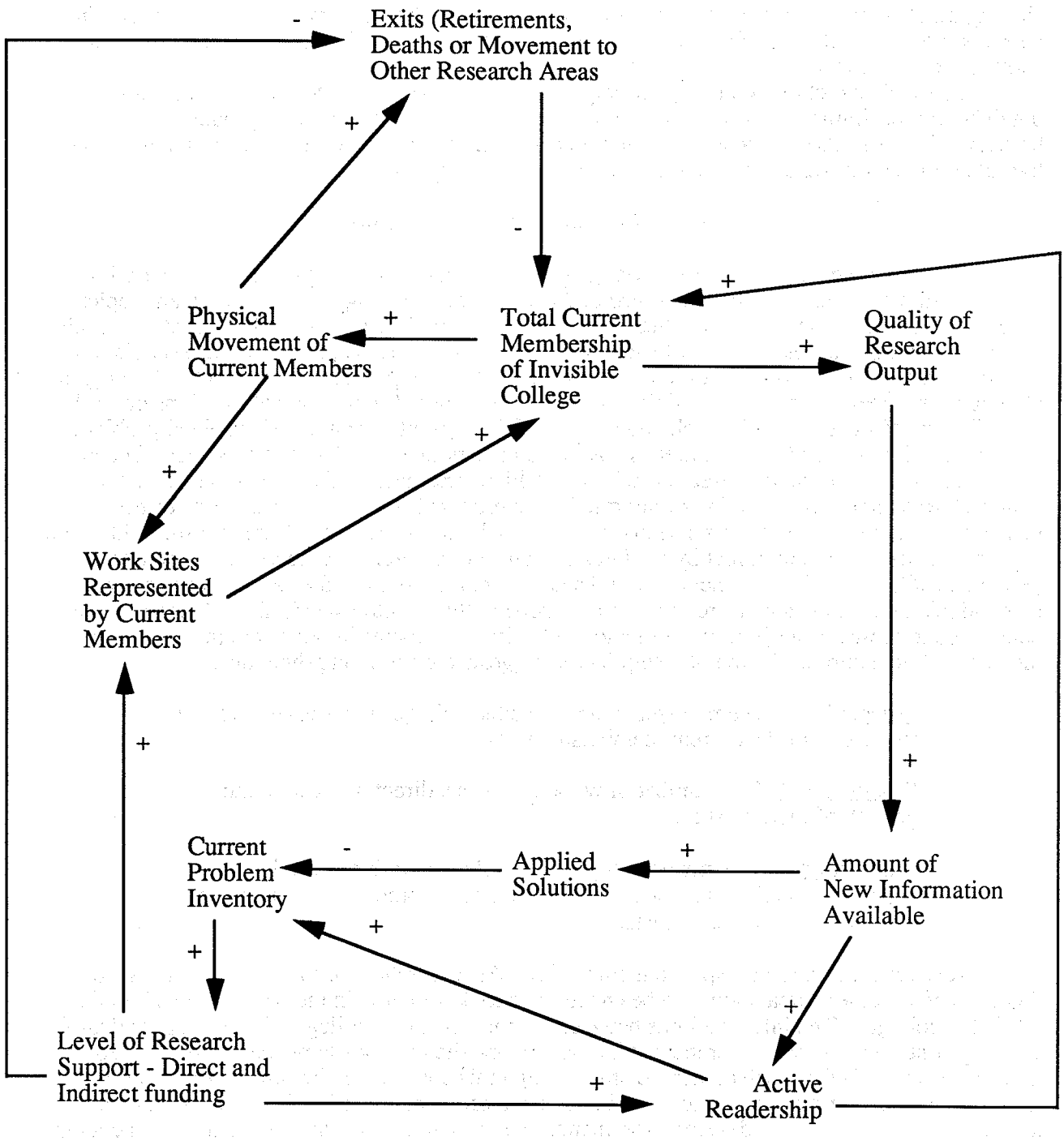

Fig. 1. Model of Diffusion of Intangible Managerial Innovation

some cases, exits occur as researchers find other areas more interesting or rewarding. Thus, the visibility of the area, which allows movement, may also result in some exits from the research area.

The absolute size of an "invisible college" is depicted as having a direct influence on research effort. For a given "college," this occurs because only a fraction of its members are actively researching in a problem area at any time. However, that fraction should remain fairly constant. Thus, the intensity of research effort may be independent of size of membership while the total volume of output is not. Such observations indicate various potential network control factors that can be employed to vary its overall performance characteristics. For instance, both the size and research intensity of a network, such as that for exploring technological change effects, may be subject to control.

Geographical Sites

The number of research sites has an affect on the level of research by the members of an "invisible college," because growth in sites acts to increase the possibilities and incentives for inquiry. Otherwise, the inbreeding of the "invisible college," suggested by the nonexpansion of work sites, would result in encrustation of ideas and the tendency to think that major lines of inquiry have been exhausted. The direct links affecting work sites, depicted in the model, suggest that:

> Proposition 4. The number of work sites in an "invisible college" increases with the movement of members.
>
> Proposition 5. The level of research funding, in a problem area, is directly related to the number of work sites represented.
>
> Proposition 6. An increase in the number of work sites will positively affect the level of membership, during all but the decline stage.

As researches move to new sites they also bring new information. Current workers at the new site may be enticed into joining the research area. This site effect may also be influenced by the tenure of a researcher within the "invisible college" because "one tends to think that the relevant issues have all been solved if one is in the field for a long time" (Crane, 1972, 37).

The level of funding for research is another important factor that influences the number of sites and relates directly to rational economic behavior. Institutions wish to be represented so that they can compete for available funds. The inventory of practical problems that remains to be solved should play a role in determining the extent of funding. Funding serves to attract researchers at unrepresented sites, who then begin to add pressure to provide funds to the research area. Interestingly, if the links between a funding source (usually an applied user) and researcher (usually a less-applied academic) are not well developed, the full transfer of "paid-for" knowledge may not occur. Thus, the problem inventory and external funding may serve as the vital link link between research and applied communities. However, "invisible colleges" have not been found to develop into scientific elites that capture the advisory systems, which can then distort the direction of funding (Mullins, 1985).

Readership

Readership refers to the level of exposure ne knowledge generated by the "invisible college" gains from its audience, its current members, users of knowledge in industry, and readers who may be in a different research network, as well as uncommitted graduate students. The dynamics most directly affecting readership suggest that:

Proposition 7. Readership is directly related to the level of research funding.

Proposition 8. There is a direct relationship between the level of membership and the level of readership.

Proposition 9. The extent.of new information produced by the members of an "invisible college" has a direct relationship with readership but the impact of this relationship progressively weakens with time.

New information may or may not attract readership. Without leaders in the area, with a long-term commitment to market this information aggressively, new readers will not be attracted. Thus, in some cases, new information may not help to increase readership and may hasten its decline. This is the case when the marginal value of new information is small and gets concentrated on narrower fields of interest. If increases in research effort lead to increases in new information it is also likely that this information gets concentrated in its focus and, over time, will decrease the level of readership that considers it relevant.

Funding support, because it acts as fuel for the research area, plays a necessary but not sufficient role in this process. Funding encourages readership and this acts to replenish and to increase the inventory of unsolved problems. Readers not only can buy into the existing agenda of problems but they can also identify new problems. Eventually this acts to rejuvenate the area.

Inventory of Unsolved Problems

The inventory of unsolved problems affects the impact of the "invisible college" on organizational performance. It is the factor, in the model,that is most directly determined by the applied community. The more direct dynamics, related to problem identification and solution attempts, suggests that:

Proposition 10. As solutions from practice increase, the inventory of unsolved problems declines, which results in a reduction of funds available to solve the remaining problems.

Proposition 11. Increases in readership leads to an increase in the number of research programs designed to address the inventory of unsolved problems.

While research provides solutions problem identification is equally important. Many solutions will come from applied settings, and this reduction in the problem inventory makes the research area less attractive. If the problem inventory is not replenished this leads to a situation where there will be continuous movement out of an "invisible college" into alternative ones, with few new members joining because applied users are less likely to fund purely exploratory research. This link between academic researchers and applied users is complex because "sharing or withholding scientific information with colleagues...is not the same activity as trying to instruct the public" (Meltsner, 1979, 331).

Total System Effects and Conclusions

Taken as a whole this model of intangible innovation diffusion requires a geographically dispersed and intellectually linked network to establish the interface needed for effective diffusion. This corresponds closely with Hagerstrand's (1967) theory that diffusion occurs through social networks that operate independently at the local, regional, national and international level. The existence of separate applied and academic communities complicates the process because it means that local links must be established with and across both groups.

The model is further complicated because both members and sites are dynamic. In addition, the model incorporates multiple factors, some of which are not empirically measurable, as relevant to the diffusion process. While only the rate of diffusion is of interest when forecasting new products, systematic relationship that affect entry and exit are central to the diffusion of managerial innovations. For example, a key area appears to be the "inventory of unsolved problems" because this acts to initialize the system, which acts as a stimulus to funding support for research.

Once research support exists, a self-supporting process begins. While there are both additions and deletions to the "invisible college" cumulative growth in both membership and work sites signals an active diffusion process. This activity also provides the research needed to address problems in the current inventory, which results in the identification of new problems. As information on a problem area is published, it begins to reach either the academic or applied communities, depending on the nature of the journal. This contact acts to reinforce the system because academic research attacks the problems inventory. Interested applied users of knowledge can, through funding, direct research efforts toward specific problems and provide information about new unrecognized problems.

From a system perspective an"invisible college" appears to operate as far more than simply a membership pool. It acts as the organizational diffusion agent by both setting the research agendas and defining the scope of research effort. Because of its influence on the inventory of problems it also appears to have a role in transferring problems and research results between the applied and academic sectors.

As the pace of knowledge development increases, and the geographic space over which this development occurs becomes larger, understanding the dynamics of diffusion will become more important. The model developed in this paper suggest that knowledge generation is a self-reinforcing process that is tied to diffusion and requires both academic and applied inputs. More importantly, it suggest that there is a relevant organizational context in which both management research and diffusion occur. Thus, while a series of research propositions were developed, inplied in the model is the suggestion that a more in depth examination of how "invisible colleges" function is needed.

Because the time frame over which these "invisible colleges" form and over which managerial innovations diffuse is long, longitudinal research is needed, but our knowledge of which data to collect and over what time frame is severely limited. It is for this reason that system dynamics modelling, and the testing of theoretical links through computer generated simulation of these models is so valuable. Simulation models of this type can be used to identify points of high leverage that provide multiplying effects, which can be used to enhance the diffusion process.

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