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The Need for Some Innovative Concepts of Innovation: An Examination of Research on the Diffusion of Innovations*

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ABSTRACT

This paper examines research on the diffusion of innovation, the final stage in the process of technological change. The focus rests primarily on two traditions in diffusion research: that of economists and that of sociologists. Diffusion researchers in these and related disciplines have made significant contributions to the understanding of the dynamics of processes of change; yet the state of the art in diffusion research is not equal to the sum of its parts. This is due in large measure to disciplinary parochialism: scholars have concentrated on those innovations, diffusion environments, explanatory variables, and analytical methodologies which are most compatible with their particular disciplines, despite the fact that diffusion is not a discipline-specific phenomenon. Deficiencies in current understanding of diffusion are examined in the context of this and other significant problems. The paper concludes by considering the policy relevance of diffusion research and suggesting issues with which future research might productively be concerned.

Introduction

Within the past few decades several economists have been investigating the processes by which technological change occurs and thereby transforms the nature of economic life: the motivations and mechanisms underlying both private and public sector research and development; the generation of technological innovations; the diffusion

* The following individuals have been most helpful in stimulating and directing my interest in this subject and in criticizing this paper: Richard R. Nelson of Yale University and the following members of the Faculty Seminar on Innovation and Social Change, Institute of Public Policy Studies, University of Michigan: Michael Moch, Lawrence Mohr, Everett Rogers, Herbert Schuette, Jack Walker, and Sidney Winter.

of innovations. While an interest in this area has existed for decades, and while the study of R&D/innovation/diffusion has certainly never been the exclusive province of economics, it is safe to say that the bulk of theoretical and empirical economic understanding of these phenomena (with particular reference to the diffusion end of the spectrum) dates from Zvi Griliches' work in the 1950s on the diffusion of hybrid corn seed [1]. Economists now have a grasp of those factors which influence technological change, which motivate research, development, and innovation, and which promote or retard diffusion throughout the relevant market.

Or do we? It is my contention that economists' knowledge of the processes of technological change is limited to a few reasonably narrow and well-defined situations; that, due in part to the situations studied and in part to the complexity of certain problems, published studies have evaded or obfuscated several fundamental conceptual issues crucial to a genuine understanding of technological change; and consequently that existing knowledge fails to explain the dynamism of much of the economy's most significant activity and offers little to those who would like to influence processes of technological change.

This paper is written in the hope of provoking interest and innovative research in the economics of technological change, with an emphasis on the diffusion of innovative technology, both "hard" (i.e., physical objects) and "soft" (i.e., programmatic and organizational changes). (The diffusion of innovation is only one stage—the final one—in the process of technological change. It is an important one, however, because it is the stage which represents the transition between the old and the new economic equilibria (see Nelson, Peck, and Kalachek [2], p. 97).) The paper is not intended to serve as a comprehensive literature review; nor does it offer solutions to the questions and problems it raises. Rather, it represents a sharing of the concerns and issues, rarely voiced in the literature, which I have encountered in my own research on the diffusion of medical innovation [3].

I should like at the outset to explicitly acknowledge the biases of this paper. The discussion is perhaps too critical of the state of the art in diffusion research, and perhaps overly optimistic about its potential. For example, it may be reasonably argued that no generally applicable substantive definition of innovation can be developed, and hence that strict comparability of different studies is an impossibility; problems such as this may require solutions which are more or less arbitrary. My purpose, then, is not to suggest the imminent development of a perfect understanding but rather to stimulate some original thinking which might advance the field beyond its current limits.

The disciplinary emphasis of this paper also requires clarification. Of the 2000-plus published diffusion studies, the great majority are the work of sociologists.[1] However, the intellectual contribution of the relatively few economists, political scientists, and other social scientists publishing in this field is considerably greater than their quantitative share of the literature would suggest, for two reasons: (1) simply, and obviously, these

[1] The most comprehensive bibliography of empirical diffusion research publications, coded by discipline, is Appendix B (pp. 387–466) in Rogers and Shoemaker [4]. The authors discuss the major intellectual traditions in diffusion research on pp. 48–70. (Rogers keeps an up-to-date annotated inventory of diffusion publications at his University of Michigan offices.)

individuals have employed and presented analytical perspectives which differ significantly from those of the main body of diffusion research, thus broadening the nature of intellectual inquiry and helping to ferret out interesting and important issues; (2) in general, the quality of these studies has been high. The present paper focuses most sharply on the work of economists because this is the literature and perspective with which I am most familiar and because, given my perspective, I am convinced that the discipline of economics—practised by itself and as a component of interdisciplinary efforts—has much to offer toward advancing understanding of the diffusion of innovation.

The paper begins with a brief sketch of the state of the art in diffusion research, in economics and in sociology and the other social sciences. The next section indicates the scope and nature of the problems which remain unresolved. The two ensuing sections focus on specific issues which illustrate the nature and complexities of the work which needs to be done. The paper concludes with a discussion of the normative and positive importance of diffusion research.

The State of the Art in Diffusion Research: Economics

Thanks to the imaginative work of Griliches [1], Mansfield [5,6,7], Hirsch [8], Arrow [9], Nelson *et al.* [2], and others, economists have a good general understanding of the roles of profitability, size of required investment, uncertainty and risk aversion, the spread of information and new knowledge (and thus learning), and other economic factors in the processes of diffusion of a certain class of successful innovations: namely, basically unchanging innovations (or, more accurately, innovations treated as such analytically)[2] which replace similar but less efficient inputs in a production process or outputs in an industry's product mix, assuming a conventional market profit orientation. For such innovations, current knowledge can be applied, with a respectable degree of success, to explain or to predict the pattern and speed of diffusion, both within firms and among firms in the relevant industries.

The empirical evidence garnered by these researchers provides strong support for the following hypotheses:

(1) *Diffusion of such innovations evinces an S-shaped pattern* (usually specified as a logistic, see Fig. 1) *similar to the snowball or chain reaction patterns documented for many processes in both the physical and social sciences.*[3]
Mathematically, the logistic looks as follows:

$$P = \frac{K}{1 + e^{-(a+bt)}}$$

[2] "Unchanging" refers to characteristics such as potential profitability, physical structure, and so on. It is clear that several of the innovations investigated in the literature are by no means unchanging, though they are treated as such for analytical simplicity. Presumably, the validity of the analysis varies indirectly with the degree of the innovation's deviation from "unchanging."

[3] Mansfield's research indicates that ". . . the same kind of model can be used to represent both the rate of diffusion among firms and the rate of diffusion within a firm. The model . . . emphasizes the same sorts of explanatory factors and is similar in structure" [5, p. 190]. The reader is asked to keep this important distinction in mind; though what follows refers explicitly to *inter*firm diffusions, most conclusions can be generalized to *intra*firm diffusion. For Mansfield's discussion of intrafirm diffusion, see [5], pp. 155–191.

where, for diffusion of innovation studies, P is the percentage of potential adopters who have adopted the innovation, K is the asymptotic ceiling (or equilibrium) value of P, t is time, a is the constant of integration locating the curve on the time scale, and b is the rate-of-growth coefficient. Adoption of the innovation by potential users increases at an accelerating rate throughout the first half of the diffusion process, reaches an inflection point (A), then increases at a decelerating rate to the asymptotic ceiling (K).

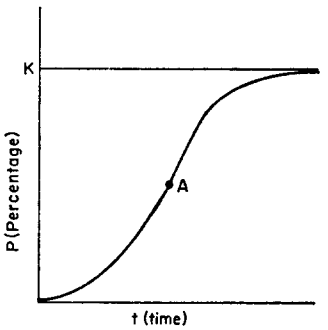

Fig. 1. The logistic.

The parameters have the following meanings: K represents the end-point of the diffusion process, the point at which all potential users who will ever adopt the innovation have adopted it. For highly valuable, easily implemented innovations for competitive industries, one can expect (and evidence indicates) that K will be approximately 100%. a serves to situate the curve on the time scale (abscissa), defining the starting point of the diffusion process. b is the rate at which potential users adopt or accept the innovation; hence b indicates the speed with which the innovation diffuses to its asymptotic ceiling. While the determinants of a and K are of definite interest,[4] economic research has centered on the determinants of b, that is, on the economic variables which affect the rate of adoption.

The model's S-shape defines the nature of the learning and imitation dynamics which are generally agreed to constitute the diffusion process; the factors which affect b determine the speed with which this path is traversed. Assuming that adequate supplies of an innovation are available, and that knowledge of the innovation's existence is widespread, the specification of the logistic implies that potential users initially approach the adoption decision with caution: that they experiment with the innovation on a trial basis (where possible) and wait for feedback—from their own experimentation and from reports of other users—on the innovation's costs, value, and so on, before deciding whether or not to adopt. Later, as more and more positive feedback accrues, both lack of knowledge of how to best use the innovation and uncertainty about the results of using it are reduced, and the pace of the adoption process increases. The nature of the learning and imitation dynamics has been em-

[4] For example, why do some innovations diffuse through only half of a prospective market (K = 50%) and others diffuse throughout the entire market (K = 100%)? The problem of determining K is usually handled by some form of "casual empiricism." See, e.g., Griliches [1], p. 504.

bedded in the mathematical diffusion model both by assumption (e.g., Griliches [1]) and by derivation (e.g., Mansfield [5], Ch. 7). However they are approached, it is clear that learning and imitation processes are central to the diffusion story; and it is certain that the last word on the subject has yet to be spoken.[5]

(2) Mansfield hypothesized ([5], pp. 146–148) that *the rate of adoption* (he calls it the rate of imitation) *is a linear function of the profitability of employing the innovation, the size of the investment required to use it, and other unspecified variables.* Not surprisingly, testing of the model provided strong support for the hypothesis: *ceteris paribus*, the more profitable the innovation and the smaller the required investment, the greater the rate of imitation. Other factors—whether or not the innovation replaces durable equipment, the rate of expansion of the relevant firms, the point in history (the assumption being that the rate of diffusion has increased over time, owing to improved channels of communication, etc.), and the phase of the business cycle—had apparent effects in the expected direction, but their inclusion in the regression analysis did not significantly improve explanations of variations in the rate of imitation; determination of their significance requires more data than Mansfield had available.

Other studies corroborate Mansfield's findings. While the effects on diffusion of economic incentives are in the anticipated directions, the question of the overall efficiency of the unfettered diffusion process remains open. Tentative answers range from Griliches' conclusion [1] that, "On the whole, taking account of uncertainty and the fact that the spread of knowledge is not instantaneous, [as concerns hybrid corn] farmers have behaved in a fashion consistent with the idea of profit maximization,"[6] to the suggestion by Nelson *et al.* [2] that risks, externalities, firm inefficiencies and the like slow the diffusion process to a less than socially optimal rate. These responses are not necessarily conflicting. An individual's behavior may be individually rational, but given market imperfections such as externalities, the aggregate of individually rational behavior need not be socially optimal.

Nelson *et al.*, in suggesting that the market diffusion process is inefficiently slow, attribute this laggardness to the inefficiencies of individual firms as much as, or more than, to inherent market imperfections. To the extent that firm inefficiencies are the major contributor to the slowness of the diffusion process, this is a reflection on market structure and not on the diffusion process *per se*. In essence, then, there is the obvious suggestion that the speed of diffusion is positively related to the competitiveness of the industry or market. "A firm may dawdle if the result is merely slower growth of profits, but it is likely to be activated when the result is a serious erosion of a previous profit or market share position. The pressures to adopt . . . innovations rapidly will be greater in reasonably competitive than in more sheltered industries" (Nelson *et al.* [2], pp. 101–102). This is the dynamic analog of the static proposition that competition fosters economic efficiency.

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[5] Nelson *et al.* ([2], pp. 97–109) present an excellent discussion of the roles of learning by doing and by observing in reducing uncertainty and thus promoting diffusion. This discussion includes a thoughtful treatment of the complex process and efficiency issues in diffusion.

[6] Griliches seems convinced that this case-specific conclusion generalizes. Following the sentence quoted above he says, "Where the evidence appears to indicate the contrary, I would predict that a closer examination of the relevant economic variables will show that the change was not as profitable as it appeared to be."

(3) Relevant to intrafirm diffusion (though the explicit context is rarely diffusion *per se*) are the several studies on learning-by-doing (manufacturing progress functions) dating from the mid-fifties. The thrust of this literature is that *efficiency in the use or production of a novel item or technique increases with experience within the firm; more specifically*, that *there is a negative linear relationship between the logarithm of labor effort expended and the logarithm of "experience"* (i.e., number of units of output produced or number of uses of input). Research on, for example, the aircraft industry done by, among others, Hirsch [8] and Alchian [10] has lent empirical support to this hypothesis.

The relevance for interfirm diffusion of learning-by-doing lies in the reduction of uncertainty and improved efficiency which accompany learning. For the individual firm, experience with an innovation, even on a small-scale experimental basis, will supply the firm with the information and knowledge it needs to best exploit the innovation. But the firm's learning has spin-offs for other firms[7]; they also learn from the first firm's experience, thus increasing their understanding of the innovation's potential and decreasing their uncertainty about adopting the innovation. As knowledge accrues, the risks associated with early adoption diminish.

The influences of learning on diffusion—on technological change in general—are profound. (Indeed, learning-by-doing concerning a specific innovation can generate knowledge about innovative behavior in general. Thus learning can foster innovative behavior as an organizational propensity by decreasing the costs of such behavior.) The economic literature has focused on one aspect of learning—the effects of experience upon efficiency—but has not explored other factors which promote or deter experimentation and hence experience. Representative of these factors, which have been considered by sociologists, is "trialability," the ease with which an innovation can be tried on a limited basis. Incorporating such factors into learning-by-doing studies is a task for the future.

(4) As is emphasized in the ensuing discussion, economists have shied away from consideration of noneconomic variables (as noneconomists have generally ignored the economic factors). The work of economists has suffered as a result, since no single discipline's variables explain the entirety of diffusion. *Diffusion is a complex social phenomenon which clearly involves both economic and noneconomic factors.* As Mansfield observes ([5], p. 172): "Perhaps these [additional economic] variables are less important than other more elusive and essentially noneconomic variables. The personality attributes, interests, training, and other characteristics of top and middle management may play a very important role in determining how quickly a firm introduces an innovation." Sociologists would undoubtedly agree. They employ as independent variables precisely such factors, as well as channels of communication and so on. Unfortunately, for the reasons discussed below, the several disciplines, generally concentrating on their individual methodologies and variables, have produced few comparable studies. Little is known about the interactive effects of economic and

[7] This assumes that the first firm either cannot or does not choose to conceal its new knowledge. If the firm can conceal the knowledge, it will likely attempt to exploit this monopoly power, either by keeping the information secret and benefiting from the competitive edge, or by selling the information to its competitors.

sociological variables. It seems reasonable, however, to assume that variables from both sets are important in explaining many diffusion processes.[8]

Obviously, there are other findings of interest, but these four hypotheses summarize several of the more prominent results of the economics diffusion literature.[9]

The Contributions of the Sociologists and Other Social Scientists

The bulk of social science diffusion research has been performed by sociologists (see the bibliographies in Rogers and Shoemaker [4] and Zaltman *et al.* [17]), with a few political scientists (such as Mohr [18], Walker [19], and Gray [20]) and others making valuable contributions to the general body of knowledge. As might be expected, though the findings of the various disciplines overlap to some extent, the intersection is small. Disciplines' perspectives differ, often radically, resulting occasionally in noncomparable analytical techniques and frequently in qualitatively different classes of independent variables (e.g., the sociologist's "channels of communication" and the economist's "profitability"). Furthermore, the *types* of innovations studied diverge significantly from discipline to discipline (e.g., programmatic innovation *versus* the new technological item). In general, sociologists have studied a far wider range of innovations than have economists, though it is not clear that the former have fully recognized the distinctions which (perhaps unconsciously) have caused economists to shy away from investigating various types of innovations (e.g., programs).[10]

The sociological literature is rich in precisely those areas where the economic literature is poor—for example, examination of the personal traits and characteristics of innovators and imitators, and detailed investigation of the communication channels through which information and new knowledge diffuse to potential adopters. Similarly, sociological studies are deficient where economic studies are strong, the former frequently ignoring the influences on diffusion of profit and loss, size of investment, and so forth. In general, sociologists have concentrated on studying characteristics related to the degree of innovativeness of individual adopters, while most of the economic work has focused on the aggregate of individual adopters' decisions, namely diffusion. The potential complementarity of the two approaches is clear, but the divergent perspectives and variables and the virtual isolation of the disciplines from

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[8] Few diffusion researchers would challenge this statement today. Griliches did so a number of years ago and triggered a fairly vitriolic exchange of articles between himself and several sociologists. The controversy is described, and references cited, in Rogers [11], pp. 136–142, and in Rogers and Shoemaker [4], p. 144 (first footnote).

[9] For a more detailed review of the scope of market diffusion research and the directions of the present economic research, see Utterback [12], and Mansfield [6] and Mansfield *et al.* [7], respectively. An exciting and novel approach to the economics of technical change is the work of Nelson, Winter, and Schuette [13, 14, 15, 16].

[10] This statement might reasonably be criticized for its parochialism. The set of characteristics which distinguish types of innovations depends on one's perspective. Thus while an economist might view hybrid corn seed and tin containers in brewing as qualitatively similar innovations—each represents an input which is substituted for another into an otherwise generally unaffected production function—the sociologist sees these innovations as significantly different, in that the former is employed by a single, independent individual (the farmer) while the latter is adopted in the context of a large industrial organization with bureaucratic chains of command and decision-making.

one another has thus far failed to produce meaningful assimilation of the ideas of the one into the thinking of the other. (Of course, there are occasional exceptions, such as the collaboration between Mason and Halter [21], a sociologist and an economist respectively.)

The sociology-political science diffusion research has examined the diffusion both of physical objects (e.g., new drugs; see Coleman *et al.* [22]) and of programs and organizational innovations (see Mohr [18], Walker [19], and Gray [20]). Emphasis has been placed on the personal traits of potential adopters (or on the collective sociological traits of multiperson adopters, such as large organizations), on the social relationships among innovators and imitators, and on the relative importance of different channels of communication. In addition, sociologists have suggested and studied significant characteristics of innovations as perceived by potential adopters. As listed by Rogers and Shoemaker [4], these include relative advantage (in objective terms—e.g., profit—and in subjective terms—e.g., the prestige-conferring qualities of the innovation); compatibility with adopters' needs and values; complexity of use and understanding of the innovation; trialability (or divisibility); and observability (the degree to which others see the results of use of an innovation; also called communicability). (Zaltman *et al.* [17] give a more comprehensive list.) The empirical evidence suggests that the expected influences do hold. Diffusion is expedited by greater relative advantage, simplicity, ready trialability, and so on.

Similarly, much has been learned about the characteristics of those who adopt innovations early and those who adopt late—the kinds of considerations which Mansfield acknowledged as potentially important but did not himself investigate thoroughly. *In toto*, the patterns of interpersonal or interorganizational diffusion which emerge from the sociologists' studies tend to be S-shaped, though, again, the explanatory variables are highly dissimilar to those employed by economists.

In summary, the diffusion of a wide range of types of innovations has been studied and a great deal has been learned about the roles of a large number of factors. However, the state of the art in diffusion research is not equal to the sum of its parts, owing in large measure to disciplinary parochialism. The need now is for researchers to recognize and acknowledge the contributions and the interests of each other's disciplines. While the payoff to interdisciplinary diffusion research would appear to be considerable, it is clear that individual scholars could improve their work simply by attempting some integration of their perspectives with those of other social sciences. Diffusion is not exclusively an economic phenomenon; nor is it purely sociological, nor political. This complexity of the diffusion phenomenon should be reflected in the mix of variables which are studied, regardless of the principal orientation of the researcher.

Yet even if interdisciplinary research managed to incorporate the diverse findings and approaches into a unified whole, the state of the art in social science's understanding of diffusion processes, processes of change, would remain unsatisfactory. Indeed, it is precisely the interdisciplinary focus which reveals the gaping inadequacies —the deficiencies and errors—in what is currently accepted as knowledge about the diffusion of innovations.

Areas of Concern

The following list enumerates several of the issues which remain unresolved or unexplored (with particular reference to economics), in order to indicate in general the depth and scope of the research problem.

1. Definitions

While everyone "knows" the meaning of words like "innovation," "adoption," and "diffusion," and every researcher has his own working definitions (e.g., those of Mansfield *et al.* [7], p. 11, Mohr [18], p. 112, and Rogers and Shoemaker [4], p. 19), there are no adequate general definitions which offer common ground for the operationalizing of concepts for research purposes. Consequently, the diversity of operational definitions restricts comparability of studies. Furthermore, as will be elaborated below, existing operational definitions of "innovation" prohibit the study of the diffusion of a whole range of innovations whose characteristics vary at any one time and change over time. (What is a *single* innovation?) Differing notions of "adoption" blur the meanings of "diffusion" from one study to the next.

The precision of specification of the innovation—the extent to which it can be strictly and unambiguously defined—introduces further complications. Consider, for example, the contrast between studying the diffusion of hybrid corn seed and studying the diffusion of PPBS (the Planning, Programming, Budgeting System) among state departments or agencies. The former is specific and well-defined; the latter means many different things to different agencies. PPBS is implemented in numerous ways: some agencies may consider themselves "adopters" by merely adopting the label, whereas others will not employ the label until they have seriously attempted to incorporate the principles of systematic analysis into their programming, planning, and budgeting.

In another vein, there is a "definitions problem" in the language employed by the various social science disciplines. In order for diffusion researchers in different disciplines to communicate effectively, a great deal of "diffusion of jargon" must take place. While this problem is hardly unique to diffusion research, it is felt most acutely in research areas which are not discipline-specific. It is clear, for example, that any economist who wishes to study the diffusion of innovation must invest significant time and effort in simply learning the relevant sociological terminology. In the present paper I have tried to limit the use of discipline-specific words, but the reader will undoubtedly pick up the flavors of at least the economist's and the sociologist's diffusion vocabularies.

2. Typing Innovations

(a) *The types studied.* When one reviews the totality of research on diffusion, one encounters a broad spectrum of types of innovations. However, within a single discipline the range is relatively narrow, resulting in sociological understanding of certain types and economic understanding of others, with little overlap. For example, economists have studied new inputs and simple outputs which are (or are treated as)

unmodified over time and whose implementation does not force substantial alteration in the character of the immediate environment. They have not investigated continuously evolving technological innovations, those in which the innovation itself changes during the process of widespread adoption; they have not looked in depth at quasi- and nonmarket technological changes, including public sector activity; nor have they ventured far into the realm of organizational or programmatic change. Sociologists and political scientists, on the other hand, have concentrated on the quasimarket and public areas, investigating novel items and programs and organization, but in only a few instances have they explored more purely economic goods and services. In general, the various disciplines have focused on those innovations which are most compatible with their perspectives and research methodologies, thus avoiding or overlooking numerous challenging conceptual problems and failing both to explore different types of innovations and even to recognize the need for a classificatory scheme.[11]

In addition, research has generally considered only successful (or "neutral")[12] innovations—those that "made it" in the relevant industries or agencies. But what about the "flops"? Economists would respond that flops do not in general diffuse very extensively. While this proposition may hold true for the competitive market cases, its validity in quasi- and nonmarket arenas is highly suspect; the phenomenon of "fads" is tremendously important in many fields. Consider, for example, esoteric medicine. With few conventional cost constraints, a professional ethic encouraging innovative behavior, and the profound dilemma of dealing with crisis situations, the medical profession has enthusiastically and widely adopted several innovations which later proved to be deleterious to patients and subsequently ceased to be used. Though medical care diverges sharply from the competitive market paradigm, its economic importance cannot be questioned; and as the continual infusion of innovative technology and practice contributes significantly to the spiraling costs of care, the diffusion of medical innovation would seem to be an apt subject for economic research. Ultimately, unsuccessful innovations may pervade many important sectors of the economy, yet we know very little about the processes of technological change in these economically unorthodox sectors.

(b) *Dimensions of an innovation.* For purposes of analysis an innovation may have many dimensions: frequently, the physical entity does not suffice as a definition of the innovation. A second dimension of obvious import is the *use* of the innovation.

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[11] Devising such a scheme is a far from trivial problem, as is acknowledged by anyone who has ever attempted the task. I confronted (but did not resolve) the problem in my working group at the National Institutes of Health Conference on the Diffusion of Medical Innovation, held September 24–27, 1972. Our group was assigned the task, among others, of developing the basis for an inventory of significant medical innovations. Given the need to solicit specific suggestions from some mix of the groups of experts (biomedical researchers, scientists, practicing physicians, other medical personnel, administrators, and consumers), no genuinely random procedure could be determined. A defined mechanism for selecting "representative" innovations was called for, but how is "representative" operationally defined? By user? By physical nature of the innovation? By economic and sociological characteristics? This is indeed a profound problem.

[12] Several sociology and political science studies have involved programs whose worth may never have been established, yet was not questioned in the context of the studies. (Indeed, the task of defining a basis for determining "worth" is frequently ignored.) The researchers in these cases were interested in diffusion irrespective of the value of the innovation. ". . . no effort was made to develop any method of determining the relative importance or desirability of the programs" (Walker [23], p. 356).

Consider, for example, Teflon. Originally developed as a corrosion-resistant material capable of withstanding high temperatures, Teflon was adopted initially for certain specific industrial purposes. It was not until later that its potential in consumer markets was recognized and Teflon-coated cookware found its way into ordinary homes. Given its great diversity of uses—in low-friction bearings, rollers for desks and doors, license-plate brackets, and so forth—attempting to analyze in the conventional manner the diffusion of Teflon *per se* would be a formidable, perhaps impossible task, and one of questionable value. Considering that Teflon has been sold in industrial, commercial, and consumer markets, for many different uses introduced at different points in its history, with more uses likely to be discovered in the future, what would one define as the appropriate adopting unit? How could a ceiling (end-point) in the diffusion process be determined, since, as more uses of Teflon are developed, its potential market grows? Clearly, any meaningful analysis of the diffusion of Teflon requires a specific usage context.

However, the mere addition of a use dimension does not suffice. Even when studying diffusion in a single usage context, the implications of an item's multiple applicability must be explored. For example, in this case the early demonstration of Teflon's qualities in industrial environments had the effect of reducing the necessary R&D, as well as the usual experimentation and learning, involved in its later employment in consumer goods.

Again, another dimension of great importance is the innovation's profitability, or, more generally, its value. While profitability is an explicit determinant of the rate of diffusion of conventional market innovations, many quasi- and nonmarket innovations cannot be evaluated in simple dollar-and-cents terms. Immeasurability problems frequently occur in analyses of public sector and private nonprofit activities; they are felt particularly acutely in the study of diffusion. Profit is a salient feature of market innovations; but what is the comparable feature of nonmarket innovations? The relevance of the question goes beyond the simple fact of measurement and definitional problems. Without an explicit profit carrot stimulating the diffusion process, does some value characteristic of the innovation substitute for monetary profit? Or is the innovation's "true worth" relegated to a secondary role, yielding to, for example, the prestige associated with being innovative, regardless of the actual value accruing to the intended beneficiaries (see Mohr [18])? Value or worth is a dimension of every innovation; where it is not readily quantifiable, and may not affect economic behavior, it merits particularly careful examination.

Considerations such as those discussed here may, of course, be treated as independent variables in the analysis, rather than as defining characteristics. The important point is simply that such considerations have rarely found their way into analysis at all.

3. The Adopting Unit

(a) *Determining the relevant adoption unit* for analysis of diffusion. This is a problem rarely addressed, simply because it is rarely thought of as a problem. In the case of an industrial input, the unit is obvious: the firms in the industry adopting the innovation (see Mansfield [5]). Similarly, for state governmental programs or policies, one looks at the records of state legislatures (Walker [19]). But what of a sophisticated new

medical treatment? One might at first take as the adopting unit those physicians who have patients with the specific medical problem attacked by the new therapeutic technique. However, the important system of referrals to specialists affects which doctors will (should) employ the therapy. Does one then look at the relevant specialists? Not necessarily, because some other (nonspecialist) physicians may believe themselves competent to administer the therapy, so that considering only the specialists will not account for the entirety of diffusion. In this case, it might be reasonable to consider the class of patients with the particular medical problem as the unit of diffusion analysis, recognizing that the actual adopters, the physicians, work within a framework of mixed cooperation (referral) and competition. Unfortunately, this approach says little about the role of specialist referral in the diffusion of medical innovation. (For further discussion of this problem, see Warner [3].)

(b) *The role of characteristics of the set of adopters.* It is generally accepted that variations among innovations in the nature and rates of their diffusion are accounted for in part by attributes of individual adopters and by formal and informal relationships among them. Sociologists have investigated several such factors; a few economic studies have examined such factors, but only at a superficial level (e.g., see Mansfield [6], pp. 16–17). In the purely economic realm, how do firm-specific economic characteristics affect the individual firm's decision, and the timing of that decision, to adopt or to reject an innovation? At the aggregate (industry-wide) level, what are the influences, if any, of degree of competitiveness within the industry, age and dynamism of the industry, size and market structure, etc.? These questions are economically tractable but have been answered only in part. More perplexing but equally important are the interunit relationships in the economically unorthodox quasi- and nonmarket areas. How does an interunit ethos of cooperation, as in the medical referral system, affect diffusion? How do governmental bureaucracies with different degrees of organizational and budgetary rigidity react to innovation? There is a multitude of interesting and important questions remaining to be investigated.

4. Conditions Surrounding Use of the Innovation

In the economic studies, the innovation generally fits neatly into an existing production function or organization, merely replacing a similar but inferior item. What are the implications of adoption if the innovation requires a major reorganization in the way things are done, particularly if the requisite changes occur over time? To be sure, potential profitability is changing (a phenomenon which has thus far largely eluded economic study but which presents few major conceptual complications), but so may be the fundamental *modus operandi*, an element as yet unexplored.

With many innovative practices (e.g., computerized accounting), the initial innovation (the computer) is of enough value to merit its adoption, though successive refinements in the item itself and in its use (hard- and software, training of programmers, etc.) induce alterations in the structure of the item employed and how it is used. Which of these changes constitute "modifications" and which are actually themselves new innovations? The line of conceptual distinction is not necessarily fine—it may be inherently arbitrary—yet in each research case that line is at least implicitly drawn. To my knowledge, this problem has never been seriously discussed in the literature.

Finally, how does the existence (and the number) of items or programs competing with the innovation affect its diffusion? Presumably, in conventional economic markets this should be reducible to a question of relative profitability, relative investment required, and so forth. But what of the less conventional markets? Consider Judicare, an experimental program under which low-income individuals can select private lawyers to handle their legal work, with the government paying the bill. (See Friedman [24], Ch. III.) Is Judicare more or less likely to be readily accepted in jurisdictions which have strong public defender programs than in those with weak public defender programs? If Judicare proved to be a more efficient means of defending the poor, the economic criterion of comparative advantage would predict more rapid acceptance in jurisdictions lacking reasonably efficient alternatives. However, one must question why discrepancies exist among jurisdictions in the first place. If weak public defender programs reflect a negative social attitude toward adequate defense for the poor, one might anticipate little receptivity to an idea such as Judicare regardless of comparative efficiency.

5. Origins of the Innovation

Market studies have examined innovations with a great variety of characteristics, but the majority of these innovations have had one important trait in common: a commercial, for-profit origin. How important is the economic incentive to promote a novel item? The link between R&D (or invention) and innovation-diffusion has thus far been largely ignored by diffusion researchers. Some investigators, particularly sociologists, have studied the sources of adopters' interest and information about specific innovations, but no one has thoroughly examined how the nature of the innovation's sources—its invention, production, promotion—affects the speed and pattern of its adoption. Does a government-sponsored innovation receive the same selling job as a private sector innovation? Do different types of promoters (producers, etc.) have systematically different approaches to selling their product? These and other questions await the interest of researchers.

The next two sections elaborate on two of these deficiencies in diffusion research in order to illustrate the nature and complexity of the issues demanding resolution if diffusion research is to fulfill its promise.

The Concept of Adoption of an Innovation

The first task in defining adoption is to determine the class of adopters. In the case of an industrial production input, the appropriate class usually appears to be the firms in the relevant industry, à la Mansfield. However, the appropriate group is not always so readily identifiable. In the case of an industrial innovation, the adoption decision-maker is also that individual (or organization) who is most directly affected by adoption. This does not always hold true, as is illustrated by the case of certain medical innovations for which a physician effectively makes the adoption decision while a patient experiences the consequences. What then is the appropriate class of adopters—physicians or patients? The answer is not always obvious.

However, even if this problem does not arise, the task of defining adoption rarely

ends with identification of the adopter group, particularly if full scale use of the innovation requires many units of it, and the innovation can thus be used simultaneously with the input it is designed to replace.[13] What constitutes adoption in such a situation? Ten percent use of the innovation? Fifty percent? Ninety percent? Obviously all such definitions are arbitrary (e.g., Griliches [1], p. 507).

Another definition presents itself which, though still arbitrary, has the advantage of being consistently and logically applicable for one class of situations, namely those where neither the innovation nor the technical elements surrounding its use change over time: adoption (as contrasted with experimentation, etc.) may be said to have occurred once the cost of (profit from) using the innovation has been minimized (maximized), irrespective of extent of use. ("Cost" or "profit" may be interpreted loosely as any measure of value relevant to the adopter.) It is generally assumed that an innovation is not used with maximal efficiency instantaneously: to find peak efficiency, experimentation and learning must occur. Efficiency is directly related to amount of experience with the innovation (whether that is a function of time or of number of uses). Thus, if the cost pattern looks like Fig. 2, adoption is said to occur at point P.

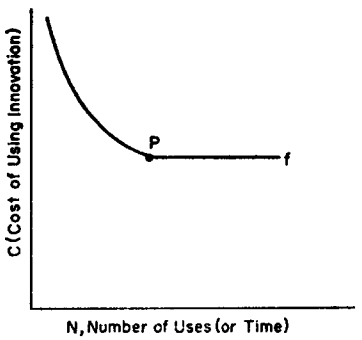

Fig. 2. Experience–efficiency cost curve.

Aside from the obvious limitations of this model (such as the fact that costs or profits may plateau several times and may even fluctuate up and down), the general concept has some theoretical aesthetic appeal. However, the model must be rejected. Owing to risk aversion a firm might reach the cost (or profit) leveling-out point before it has used the innovation at all extensively; conversely, another risk-seeking firm might employ the innovation extensively and exclusively well before point P is reached. Surely these cases do not equally indicate adoption. Furthermore, if the innovation represents a significant improvement over its predecessor, economic theory would predict its hearty, wide-spread acceptance early in the game, even well before its maximally efficient use is achieved.

It may well be that the definition of adoption must remain arbitrary, but if a generally acceptable convention could be established, different studies would thereby become

[13] The task of defining adoption may indeed end at this first stage if the innovation is so large, expensive, etc., as to be either fully utilized in production or not used at all.

comparable, at least in this dimension. *Ceteris paribus*, the speed (and conceivably the pattern) of diffusion will differ among studies employing differing notions of adoption. The field would benefit from researchers' agreeing to employ a limited set of guidelines. The problem has never been even partially resolved in the literature; indeed, it has seldom been seriously discussed.

Modification Versus New Innovation

Many of the most significant innovations find their way into the mainstream of economic life while undergoing a continual or sporadic technological evolutionary process, one which need not cease once diffusion is complete. This is true of inputs and outputs, products and programs. Examples are easy to come by: color television, computers, automatic engines, cancer therapies, state-supported public education, and so on, *ad infinitum*.

How does an analyst take these changes into account? Are they minor modifications or are they themselves innovations replacing their closely related predecessors? In the former case, one might be content to chart the diffusion process as though the product (or program) was the same entity as before, simply acknowledging the modification. In the latter case, one fears that an analysis of the diffusion of the generic innovation actually represents the aggregation of two or more fairly independent diffusion processes. For purposes of analysis, how can one differentiate? And if one could differentiate, how would one then proceed with the analysis?

Again, as with the definition of adoption, there is no nonarbitrary line which can be drawn; but here the problem is even more severe, for the arbitrary resolution has been *de facto* to ignore the problem. Economists have evaded the problem by largely restricting their investigations to innovations which do not change significantly over time (or which are treated as unchanging); that is, the evolutionary process ceases at the end of the pre-adoption developmental stage. As a result, very little is known about the diffusion of several classes of goods of tremendous economic importance, including virtually all major consumer durables. Many sociologists and political scientists have not handled the problem so deftly; they have merely acted as if it did not exist. They have studied the diffusion of innumerable programmatic innovations, while allowing the existence of a common label to conceal the diversities inherent in these programs. Thus, as noted above, some governmental agencies responding that they do indeed use PPBS may use no more than the label, others will have a single individual or two doing PPBS, and still others will have a large, trained staff implementing the concept.

Until a method is developed to make the innovation-evolution problem manageable, neither economists nor producers will know, for example, how much of the recent boom in color TV is due simply to consumer acceptance of the phenomenon, how much to the lower costs of production in comparison with past years, how much to increased consumer affluence, how much to improved reception, how much to greater mechanical reliability, and so on. Given the same price as today's product, to both consumer and producer, would manufacturers have been able to sell as many color TV's if the solid state technology had not been developed?

The Importance of Diffusion Research—A Digression

Diffusion research is clearly of significant intellectual interest: to confirm this, one need only look at the extensive diffusion literature in social science. Its heuristic value has been established by dialogs both within and outside the academic community.

Both the inherent applicability of and the desire to use the results of diffusion research vary from discipline to discipline. It would appear that economists have less interest in using the results (for other than prediction) than do sociologists and political scientists, who in turn have less interest than do nonacademicians (e.g., business firms and federal government agencies). To economists, diffusion research has been basically a positive science, a descriptive endeavor devoid of the normative or prescriptive element; this is appropriate, given the generally competitive economic nature of the markets studied.[14] For many other social scientists and policy makers, focusing on quasi- and nonmarket areas, diffusion research is discussed in the same breath with intervention theory and techniques. At the 1972 National Institutes of Health Conference on the Diffusion of Medical Innovations, it was clear that the goal of the Institutes is to encourage the development of new understanding which can be *used* to expedite or retard the diffusion of "good" and "bad" medical innovations, respectively. Indeed, one of the Conference's five working groups was called "Organizational Intervention"; it was charged to ". . . review . . . the state of the art in intervention techniques. This will inventory and assess the significant strategies for intervention which could be employed to facilitate diffusions of innovations in organizations" (NIH [25], p. ii). In the public and quasi-public sectors, and in imperfectly competitive private markets, either equity or efficiency or both may be impaired; conventional economic incentives and constraints are often inoperative, owing to market imperfections and/or conscious social choice. Innovations which might diffuse in a reasonably efficient manner in a private market are less likely to do so in these arenas; or there may be an explicit reason (politics, equity, etc.) why a solution resembling that of the market is deemed unsatisfactory. For the sake of efficiency or equity decision-makers may wish to hasten or retard the diffusion of specific innovations.

Existing knowledge about diffusion is not adequate to provide satisfactory advice to those who wish to intervene in diffusion processes. The nature both of the processes and of the significant independent variables which can be effectively manipulated needs to be understood. Too little is known, and much of what is known is, for the reasons enumerated above, neither strictly comparable with related findings nor amenable to the necessary generalization. It may be said, however, that sociologists and political scientists have contributed some useful information, simply by virtue of focusing on several of the areas in which intervention is desired. Economists, on the other hand, have not examined diffusion processes in the relevant markets and thus, at this stage, have little to offer to the policy makers. To the extent that economic vari-

[14] No implication is by any means intended that all, or even most, economists believe that the market system, left to its own devices, will produce the optimal rate and kind of technological change; as this point, very little is known about the efficiency of dynamic competitive market phenomena. Rather, the reference here is to the fact that, for ordinary goods and services produced and sold in competitive markets, there is no compelling reason for governmental interference.

ables influence diffusion in these markets, and given that the other social scientists have largely ignored these factors, this is most unfortunate. It is also an implicit mandate for intellectual action.

Where Do We Go From Here?

Despite the valuable work done to date, many aspects of the diffusion of innovations remain virgin research territory. Both conceptual work and empirical research cry out for attention and promise rewards in the forms of enhanced theoretical understanding of dynamic social phenomena and of useful new knowledge. All social science disciplines have an interest in diffusion; economics has a special stake in understanding the economic dynamism of the processes of the technological change which characterizes so much of twentieth-century life. That much of that change occurs in difficult-to-analyze quasi- and nonmarkets does not exempt economists from this intellectual responsibility: a huge and growing amount of economic activity takes place in other than the competitive marketplace.

This paper has suggested areas of deficiency in diffusion research and the importance of remedying those deficiencies. No pretense of having any of the answers has been made. The only claim to "expertise" is that of some understanding of the breadth and depth of unresolved issues. This paper has been written to share these concerns and to solicit the interest of economists and other social scientists in seeking some answers.

The general issues have been outlined and the nature of the needed research is, it is hoped, clear. Before the sorely needed empirical work can be undertaken, considerable effort must be devoted to basic conceptualization and theorizing. Researchers and, ultimately, policy makers will benefit from general though substantive definitions of commonly used words such as "innovation" and "adoption," definitions which can be operationalized with reasonable uniformity so that future studies will share a common starting point. The analytically relevant dimensions of an innovation need to be explored (its "physical" existence, its use in the context of the study, its alternative uses and their relationship to present use, etc.). We must learn how to handle analytically changes over time in the conditions surrounding use of the innovation, including supply constraints, shifts in production functions and in ancillary requirements, and modifications in the innovation itself. With regard to the latter, some workable means must be developed to distinguish modifications from what are effectively new innovations. In either case, problems of diffusion studies actually involving aggregation of diverse diffusion processes must be addressed. And so on.

Empirical research will flesh out the theoretical skeleton. In addition to the heuristic value of testing the theory—and suggesting the relative importance of independent variables—empirical work holds the promise of providing policy makers with the ability to facilitate the diffusion of innovations (or information about innovations) believed to be in the public interest. Empirical diffusion research by economists, ideally in cooperation with other social scientists, should branch out into economically unexplored areas, including continually evolving market innovations and quasi- and nonmarket innovations; novel programs and organizations, as well as physical items, merit examination. The effects of obstacles to diffusion, such as supply constraints or changing production functions, also deserve empirical attention. Finally, where

conventional economic incentives and constraints are inoperative or only partially so (as in the quasi-market and public goods areas), the diffusion of innovations which ultimately prove to be unsuccessful requires study; this is especially important for those individuals who wish to intervene in unfettered diffusion processes. How do failures diffuse? Do these processes provide clues as to what will and what will not prove successful? Considering the danger of promoting worthless or deleterious innovations, at what stage should intervention be considered a viable option? To date there is no empirical evidence, much less theory, to guide the would-be interventionist.

Economists have made great strides in developing an understanding of the dynamics of technological change since Joseph Schumpeter [26], to whom the discipline owes a special debt, offered his provocative thoughts on the subject. But much remains to be learned. Examining the professional literature, one concludes that the art of research on diffusion and other aspects of technological change has advanced from infancy to adolescence. This paper is written in the spirit of wishing to see this field continue to grow to adulthood.

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