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TECHNOLOGICAL DIFFUSION IN INDUSTRY: RESEARCH NEEDS AND SHORTCOMINGS*

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ADVANCES in technology are widely regarded as major sources of improvements in the competitive positions of firms and industries as well as of increases in national economic growth rates and standards of living. Because the benefits of such advances obviously depend on the extent to which they are utilized, considerable research has been focused on the diffusion of technological innovations. Most of these studies have sought to measure the dimensions of technological diffusion and to explain differences in diffusion patterns among innovations, industries and nations as well as changes in such patterns over time. As is to be expected during the exploratory probing of major new problems, however, the most valuable contributions made so far have been to reveal the need for more penetrating concepts, better measures, more comprehensive analytical frameworks and wider samplings of the variegated phenomena to be encompassed. Shortcomings in the theoretical work have seldom been directly harmful to industrial managements because they rely on their own more detailed knowledge of the relevant facts and problems. But such research reports have tended to mislead government officials and scholars concerning the depth and accuracy of our understanding of the causes and effects of differences among, and changes in, observed diffusion patterns. The following paper surveys the literature of the past 20–25 years in this area, and provides a critique of some of its shortcomings.[1]

I. SOME SHORTCOMINGS IN ANALYZING DIFFUSION PATTERNS

Analyses of technological diffusion rates in industry rest on three basic concepts. These concern the innovation being studied, the aspects of diffusion reflected by the measures used, and the extent of prospective applications which underlie evaluations of observed diffusion rates. Inadequacies in

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[1] References are intended merely to illustrate the issues raised by citing some reasonably well-known studies rather than to attempt complete coverage of the quite voluminous array of publications cited in my previous work, especially Gold (1971, 1975, 1977c) as well as those included in the comprehensive bibliographies of Rogers (1962), Kennedy and Thirlwall (1972), Freeman (1974), Nabseth and Ray (1974) and Kelly, Kranzberg *et al.*, Vols. III and IV (1975). Journal articles later included in collections of such papers are cited by date of the original publication followed by the date and pages in the later collection.

these conceptual foundations constitute one of the major sources of limitations on the usefulness of reported findings.

A. *Defining the Innovation*

Most important innovations emerge in a variety of forms during their early development.[2] And even after one or a few forms become dominant, each continues to undergo numerous kinds of changes. The objectives of such progressive modifications are to increase the net attractiveness of the innovation to an expanding array of prospective adopters. Resulting improvements may involve increases in realiability, in operating quality and efficiency, in other service capabilities and in the range of available sizes and special purpose models along with reductions in investment requirements, operating costs, hazards in use and other detrimental characteristics. From the standpoint of enhancing the effectiveness of diffusion studies, it should be emphasized that the significance of the innovational modifications to be recognized depends not on whether they derive from 'major' or 'minor' technological advances, but on the extent to which they increase the net advantages of applications and thus expand the population of prospective adopters.

Recognition of the need to replace the essentially static concept of a given innovation, implicit in most studies of diffusion, by a more realistic recognition of the likelihood of significant improvements over time has several important implications. First, changes in diffusion rates over time, and differences in diffusion rates among innovations, may be due in large measure to the extent of technological changes in the innovations being studied rather than to changes in the receptiveness of prospective adopters to the unaltered innovations. Second, rapid technological changes may actually inhibit diffusion rates as prospective adopters seek to avoid forms of innovation which may be superseded before long. Third, different types of technological improvements may affect quite different sectors of operations and costs—the significance of which will be discussed later. Moreover, there is a need for considerable knowledge of the technology of the innovations being studied, if modifications significant enough to affect adoption rates are to be identified instead of being overlooked, thereby preventing misinterpretation of the causes of accompanying changes in diffusion rates.

[2] This fact is widely recognized among those who have studied actual technological innovations in industry instead of 'technical change' in general. For example, see Gold *et al.* (1970, 1975b, p. 146), Freeman (1973, p. 243, and 1974, p. 47 and repeated instances through p. 157) and Nabseth and Ray (1974, pp. 4, 295). An especially penetrating analysis supported by a wide range of historical illustrations is provided by Rosenberg (1972, 1976, pp. 191–202). But seldom have data been disaggregated so as to differentiate between the diffusion rates of successive embodied stages in 'the' innovation's development. Indeed, Schenk (1974, pp. 232 *et seq.*) fails even to distinguish consistently between continuous billet and slab casting despite major differences in their technical development, capabilities, costs and other characteristics (cf. Rosegger, 1979).

B. *Measuring and Evaluating Diffusion Rates*

Another sector of conceptual inadequacy is reflected by the measures of diffusion which are most commonly used. Counting the number of plants or firms using the innovation obviously fails to indicate whether these represent only limited developmental applications or pervasive commitments.[3] Measuring the output associated with the innovation provides a more effective reflection of the extent of its utilization, but provides no basis for determining whether any given output represents high or low levels of diffusion of the particular innovation being studied[4]—yet this is a prime focus of evaluative efforts. Basing such evaluations on the proportion of the total output of the seemingly relevant industrial groups attributable to the innovation, however, involves the vulnerable assumption that it is advantageously applicable to all production in such groups.[5]

The resulting conceptual problem to be dealt with has three roots. Field research demonstrates that, in most industries, plants differ from one another in numerous important respects affecting their relative competitive positions. Such differences may relate to product designs, product-mix, the pattern of buy-or-make arrangements, equipment characteristics and modernity, quality standards, scale of production, various locational advantages and disadvantages involving access to needed inputs and markets, and capacity utilization variations as well as to managerial objectives and financial resources. In addition, most technological innovations—whether focused on the process or the product—exert their primary impacts on particular segments rather than the entire array of production operations. Consequently, the net economic advantage of any such innovation is likely to differ significantly among all plants making the general category of products and using the general type of technology affected by the innovation.[6] The population of prospective adopters of the innovation should,

[3] Nevertheless, this measure has been used with considerable frequency—sometimes further restricted to major firms alone—because of the difficulties encountered in obtaining the data needed for more penetrating measures of the role of an innovation in the relevant sector of industrial operations. For example, see Mansfield (1961, 1968, pp. 133 *et seq.*, and 1963a, 1968, p. 158), Adams and Dirlam (1966, pp. 175 *et seq.*), Nabseth (1973, p. 257), Håkanson (1974, pp. 60, 66–7), Lacci *et al.* (1974, pp. 108–9) and Smith (1974, p. 255).

[4] The use of aggregate output measures may be illustrated by Lynn (1966, p. II-41) and Ray (1974, p. 207). A related alternative relies instead on the total number of machines embodying the innovation, e.g. Gebhardt and Hatzold (1974, pp. 31–6) and Smith (1974, p. 258).

[5] Illustrative use of such measures include Gold *et al.* (1970, 1975b, pp. 130–2), Meyer and Herregat (1974, p. 153), Ray (1974, p. 220) and Shenk (1974, p. 241). Other measures of relative penetration include the proportion of all machines which embody the innovation—Gebhardt and Hatzold (1974, p. 33) and Håkanson (1974, pp. 78–9)—and the latter also provides data on the proportion of all plants and of all companies utilizing the innovation. Finally, it may be of interest to note that Lynn (1966, p. II-41) used their percentage contribution to the gross national product to measure the impact of new industries, a concept representing still another aspect of technological diffusion.

[6] There has been increasing recognition of the significance of such differences in recent years as purely statistical studies have increasingly given way to field research. General citations include Gold *et al.* (1970, 1975b, pp. 142–4) and Ray (1974, p. 13), while specific citations in Nabseth and Ray (1974) are found in the papers by Gebhardt and Hatzold (pp. 159–61), by Schenk (p. 243) and by Smith (pp. 253–4).

therefore, be conceived of as a distribution of plants whose prospective benefits from adopting the innovation often cover a wide range between the very attractive and the marginal.

Such a replacement of the concept of an essentially fixed array of prospective adopters, as determined by basically superficial criteria, offers a second set of contributions to the development of a dynamic framework for analyzing changes in diffusion patterns. For example, it supplements the earlier recognition of the dynamics of innovational developments by showing how even seemingly modest technological improvements can have significant effects on adoption decisions, for these may require only small increases in past evaluations of the innovation's net economic advantage to any given firm instead of the major revaluations that would seem necessary to reverse ostensibly outright rejections in the past. This concept also suggests that adoption decisions may be revised not only because of modifications in the innovation, but also because of changes in such factors as product-mix, capacity utilization and the other potentially distinctive characteristics mentioned above.[7] In addition, this view points to the desirability of digging beneath the prevailing emphasis on aggregate adoption data to uncover the changing pattern of adoptions as between large and small plants, those differing significantly in product-mix, plants located in different regions, etc.—and thereby eliciting further bases for estimating the particular form of additional benefits offered by successive technological improvements.

Taken together, recognition of the dynamics of technological improvements in an innovation and of changes in a firm's evaluation of the available forms of any innovation, reveal a fundamental weakness in 'saturation models' of technological diffusion in industry. Such models rest on the implicit static assumption that the diffusion levels reached in later years also represented active adoption prospects during earlier years. But this may be quite untrue, as has already been noted, because the realistic number of prospective adopters may have grown substantially as a result of improvements which increased both the range and the benefits of applications of earlier forms of the innovation and also as a result of changes in the non-technological pressures faced by firms which were initially uninterested in the innovation. It is entirely conceivable, therefore, that the increasing diffusion of a technological innovation represents less an increased saturation of initially active prospects than an increase in the array of realistic prospects for the reasons just cited. Conversely, it might even be argued that the diffusion level in any period tends to approach reasonably close to the realistic adoption potentials (or saturation) under then prevailing

[7] For an illustration of the problems of estimating the population of potential adopters of an innovation, see the chart depicting the overlapping diffusion of competing innovations in Enos (1962, p. 261).

conditions—thereby altering the usual graphical presentation somewhat as in Figure 1.

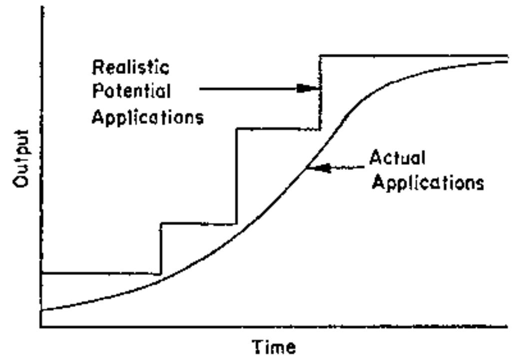

FIGURE 1. Dynamic Model of Diffusion Rates

Such a revision of the conceptual bases for measuring diffusion rates also suggests a need to re-examine: the validity of sigmoid curves in generalizing diffusion patterns; their interpretation; and some of the further uses to which they have been put. With respect to the first of these, Ray reported in 1969 that in an international study of the diffusion of various technological innovations in industry, 'Neither the curves for individual processes nor their aggregation provided any strong contradiction of this assumption' (i.e. 'that the diffusion curves are linear'). Nor was any support for the general applicability of sigmoid diffusion curves provided by a 1970 publication covering the first 15 years after commercialization of the diffusion of 14 major innovations in steel, coal and iron mining in the United States [25]. And in a later summary of the product discussed by Ray, Nabseth commented that the wide use of sigmoid diffusion curves raises two questions: 'whether such curves give a good statistical fit to the observed data' and 'how should this particular shape be interpreted' when 'the measure of diffusion is a ratio for which the appropriate denominator (i.e. realistic population of prospective adopters) is difficult to find'.[8]

But this is precisely the problem which is the focus of the revised conception. The eventual population of prospective adopters of some vaguely conceived cluster of innovational developments is replaced in the denominator of the diffusion measure by successively adjusted estimates of prospective adopters corresponding to changes over time in the capabilities of 'the' innovation and in the needs and resources of potential users. The resulting subdivision of the notionally 'over-all' diffusion pattern into components representing shorter periods tends to undermine the usefulness of the sigmoid curves both as representations of diffusion patterns within

[8] See Ray (1969, 1974, p. 16), and Nabseth and Ray (1974, p. 298).

shorter periods (as compared with linear models) and as providing analytically persuasive bases for forecasting diffusion rates for future periods likely to be characterized by still unpredictable technological and market changes.

This revised conception also suggests that a slower diffusion rate, or the slowing down of a past diffusion rate, cannot be judged as desirable or undesirable until its causes are determined—whether due to an inability to effect further applications, or to new factors reducing or diverting the interests of prospective adopters, or to restrictions on the availability of the knowledge or hardware required for additional applications. Such consideration of changes in realistic potentials based on the loci of attractive net benefits also offers more persuasive explanations of why many innovations never achieve high levels of saturation within the seemingly relevant industry sector.

C. *Determining the Applicability Potentials of a Technological Innovation in Industry*

One of the fundamental objectives of studies of technological diffusion in industry is to determine the rate and the extent of adoptions of any given innovations by those to whom it offers significant net benefits. Hence, continued widespread reliance on superficial assumptions concerning the scope of an innovation's realistic applicability have represented a critical weakness of such studies, have been a source of ill-founded but harmful criticism of seemingly inadequate diffusion rates, and have also diverted attention from research objectives which may prove more productive of policy guides than those which have dominated past studies.

To correct such shortcomings would require a comprehensive program (centering around the following undertakings for any given technological innovation:

1. determine the specific advantages, disadvantages and limitations of a given form of the innovation as compared with the equipment and practices which it would be expected to replace;
2. identify the sectors of industry currently relying on such threatened arrangements;
3. estimate the prospective net economic advantage of the innovation relative to existing practices for various subgroups of plants taking account of their competitive position, product-mix, scale of operations, capacity utilization, input availabilities, etc.;
4. indicate which subgroups are likely to gain large enough economic advantages from adopting the given form of the innovation to more than offset the accompanying delays, costs and possible internal turmoil involved in introducing the innovation, to achieve effective functioning and reach profitable levels of utilization; and
5. explore the possibility that this innovation may also attract new entrants into the industry.

Such analyses would also provide the basis for estimating probable adjustments in the array of prospective adopters resulting from future changes in the characteristics of firms, such as those illustrated in 3 above. Finally, estimates of changes in the advantages, disadvantages and limitations of the innovation resulting from future improvements would then be utilized to revise the result of each of the steps in the above analytical sequence and thus to revise diffusion prospects.

It is recognized that the foregoing research tasks may well be regarded as worrisome in their scale and in the needed depth of penetration. But presenting them should help to clarify the actual requirements for replacing the essentially descriptive findings combined with highly vulnerable interpretations which have dominated most of the literature on the diffusion of technological innovations in industry. Even identifying the realistic industrial locus of active decisions about adopting a given innovation, however, is not enough. In order to provide more useful guidance for policy making by government agencies and by industrial managements, research must provide fuller understanding about the bases on which those facing such decisions choose to adopt or to reject or to defer action, about why firms within the category of active prospects arrive at different decisions, and about the probable effect on such decisions of alternative future developments.

There are two additional aspects of technological diffusion in industry which might yield valuable perspectives for policy making if more effective research efforts were directed to their exploration. One of these involves determination of the effects of increasing diffusion of an innovation not only on its adopters, but also on non-adopters, on the suppliers to and the customers of adopters, and on the relevant factor and product markets as well as on the communities in which adopters are located. Such wider repercussions may have important implications for firms and government agencies concerned with raw materials and energy demand, capital requirements, employment opportunities, price competition and concentration as well as with employee health, product safety and environmental pollution. The other involves analyses of the estimated benefits and burdens associated with faster or slower rates of diffusion—not only on the basis of hindsight evaluations of more successful and less successful innovations, but also on the basis of judgements made at successive stages of diffusion including relatively early periods. Neither has been explored systematically with much frequency. Both represent further illustrations of the need to shift from a static to a dynamic framework.

Instead of seeking to determine 'the' effects of diffusion, the objective should be to determine the 'changing pattern of effects' resulting from increasing interactions between the innovation, associated sectors of production operations, and product and factor markets. This means that the comparison of results with expectations would be likely to yield different evaluations at successive stages of diffusion.[9] And such changing results might be expected to alter the evaluations of firms still considering whether to adopt the innovation.

Exploration of the benefits and burdens of slower versus faster diffusion might also help to throw much needed light on the hazards both of accepting hindsight judgements about past results and of generalizing about optimal diffusion rates from one innovation to another.[10]

II. SOME SHORTCOMINGS IN EXPLAINING DIFFUSION PATTERNS

Technological diffusion rates in industry are determined in the United States and in other essentially private economies by managerial decisions at the level of individual firms. And the guiding basis for such decisions is a comparison of the estimated effects on the performance of the firm over an extended period of adopting any particular innovation as against allocating available resources to other means of dealing with its problems and opportunities. Understanding such decisions accordingly requires some grasp of the larger decision-making framework of firms within which decisions about innovations represent only an occasional intermediate stage rather than a continuous independent process. In addition to clarifying such intrafirm evaluation procedures, however, an explanation of diffusion rates also requires efforts to account for interfirm differences in the decisions arrived at—thereby allowing consideration of the 'firm-specific' factors, including its distinctive pressures and managerial objectives, which may overshadow the firm's general economic characteristics in influencing the direction and timing of adoption decisions.

A. *On the Decision-making Context of Individual Innovation Evaluations*

Even the relatively few diffusion studies which seek to determine why particular firms adopted or rejected an innovation tend to foreshorten needed analytical perspectives by focusing immediately on attendant evaluations of the particular innovation. But this overlooks the frequently dominant, and always important, role of what I have called 'the pre-decision environment'.[11]

Major elements of this environment would include: the specific nature and the relative urgency of the major needs to be dealt with over the

[9] See Gold (1955, pp. 202–34, 248–50, 1964a, 1971, pp. 180–207 and 1976b, pp. 1–3, 10–27). This view is plainly in contrast to the single-valued evaluations provided by Mansfield (1961, 1963a, 1968, pp. 143, 159–60, 182) and by most of the studies included in Nabseth and Ray (1974).

[10] Cf. Williams (1973, p. xvii) and Gold (1977c, pp. 185–6). Also note the contrasting evaluations of the rate of diffusion of the basic oxygen process in the U.S. steel industry by Adams and Dirlam (1966), Maddala and Knight (1967), Dilley and McBride (1967) and Meyer and Herregat (1974) regarding their too simple evaluations of the rate of diffusion of the basic oxygen process in the US steel industry.

[11] See Gold (1967, 1971, pp. 218–28) and Gold *et al.* (1970, 1975b, pp. 142–3).

period covered by the firm's capital planning horizon; the availability and relative advantages of non-technological as well as technological means of meeting such needs; and the extent of technical, managerial and financial resources available for allocation to such efforts. In view of such a broad range of potential differences in managerial concerns, there is obviously little basis for assuming that all firms in the seemingly relevant industrial grouping are even giving serious consideration to the same innovation within any given year. Nevertheless, few executives are likely to profess indifference if asked directly about a particular innovation, lest it be interpreted as evidence of stodginess or ignorance.

Even when managerial attention is directed to a given innovation, however, common evaluation processes include several types of considerations which may result in different outcomes for reasons other than disagreements about the technological capabilities of the innovation. One of these involves analyzing its prospective operational as well as economic benefits and burdens over the period of its expected utilization. This would require taking account of those specific needs of the firm which the particular innovation would be expected to help fulfil, including such possibilities as improving product capabilities and quality, offsetting stringencies in the supply or changes in the quality of purchased materials and supplies, redressing imbalances in production flows, reducing input requirements per unit of output and altering product-mix potentials. Another set of considerations concerns the firm's market prospects, its effective capacity and the modernity of its facilities, which would jointly determine whether the adoption decision involved expanding capacity, or replacing already depreciated equipment, or displacing more recent and only partly depreciated capital goods. Still other influential considerations include possible difficulties or delays in effecting the changes that would be required by the innovation in respect to prevailing sources of material supplies, skill composition and employment levels of the labor force, and marketing and distribution activities. In addition to exploring the probable nature and extent of such benefits and burdens, it would obviously be necessary to estimate their respective effects on operating costs over time as well as other aspects of the firm's competitive position.[12]

A second 'firm-specific' consideration concerns the availability of the financial and technical resources required to adopt and to achieve effective functioning of the innovation, along with management's evaluation of the effect of such commitments on restricting its ability to respond effectively to future pressures and opportunities. And a third potentially distinctive element of such evaluation relates to the firm's assessment of the potential advantages and disadvantages of adoption at this time as over against delaying such action—considering the possibilities of further improvements

[12] See Gold (1955, pp. 178–232) and Gold *et al.* (1970, 1975b, pp. 136–9, 142–4).

in the innovation and the costs of lagging behind pioneering competitors, as well as expected changes in the availability to the firm of needed resources.

B. *On the Relative Roles of 'Innovation–Push' versus 'Needs–Pull'*

Considerable research has been devoted recently to determining to what extent the speed and level of diffusion of a technological innovation are affected by whether it was developed as a result of the initiatives of a firm's research and development staff or of customer expressions of need.[13] However, most resulting reports on the proportion of 'successful' innovations attributable to one or the other seem to be vulnerable on several grounds.

First, commercially important innovations are usually the outcome of a process involving: initial research budget allocations among alternative project possibilities; nourishing promising early developments with additional resources; transforming resulting laboratory processes or products into commercially available output through the design of various sizes and models of products and the construction or adaptation of suitable production facilities; and allocating additional resources to developing or adjusting marketing and distribution programs. Accordingly, identifying the original source of 'the idea', even if it could be done authoritatively, is likely to be of far less significance in accounting for eventual success than the effectiveness with which both technological feasibility and prospective market potentials are evaluated at successive stages of this innovational process. Thus, increasing recognition and clarification of technological possibilities and assessments of relevant market needs tend to interact rather than constituting alternative sources of stimulus to innovation development efforts. This raises the important question of how their relative influence should change in successive stages—lest a prematurely heavy weighting of market uncertainties inhibit technological developments whose fruition might expand market potentials; and lest an over-weighting of attractive market potentials minimize adequate consideration of persistent technological shortcomings.

Studies of the relative influence of research initiatives as against expressed customer needs in determining the speed and level of a technological innovation's diffusion in industry have also been weakened either by lumping together a wide variety of innovations and application sectors or by offering excessively broad generalizations on the basis of obviously restricted samples. Common experience would seem to suggest, for example, that the relative influence of these two factors is unlikely to be the same as among technological innovations seeking:

1. to reduce the cost of existing products and processes;
2. to improve existing products so as to better fulfil the needs of existing customers;

[13] For example, see Mansfield (1973, p. 206), Freeman (1974, pp. 165–70, 193–5), Teubal (1979), Holt (1976), von Hippel (1976, 1977), and Rubinstein and Ettlie (1977).

3. to develop new processes or products for completely new and hitherto non-existent markets; and
4. to develop new processes so as to utilize new developments by suppliers.

Finally, the above listing of innovational objectives also suggests that careful analysis of the sources of innovational pressure, and of their potential effects on diffusion, requires reaching beyond the two emphasized above. Other internal sources might include contributions by production engineering and product design staffs, which are separate from research and development. One of the important external sources, other than customers, consists of improvements by suppliers of materials or capital goods which require internal developments to harness resulting new potentials effectively. Other important external sources include competitors as well as independent developers.

C. *On the Superficiality of Common Explanatory Variables*

It is understandable, of course, that initial efforts to explain diffusion patterns would rely on the generalized insights offered by statistical analyses at the necessarily aggregative levels at which such data are published. But even the preceding brief summary of the variety of firm-specific considerations likely to have an influential bearing on the outcome of adoption decisions emphasizes the importance of closer analysis of the determinants of such actions.[14]

Because of the difficulties of gaining more penetrating insights into the motivations and evaluative efforts of the managerial personnel making adoption decisions, there has been widespread reliance on logically relevant but overly generalized explanatory criteria. To say that major innovational decisions are based on profitability expectations adjusted for the estimated probabilities of adverse outcomes may be unobjectionable, and may even be correct in some sense; but it is certainly unenlightening.[15] As an 'explanation' of past decisions, it offers nothing more than a tautology: i.e. if an innovation was adopted by a profit-seeking enterprise, its management must have expected its probable profitability to be attractive; and if not, not. And as an empirical 'test' of such expectations, it is hardly more helpful to demonstrate that the innovations which survive and achieve reasonably wide diffusion are those whose utilization has been associated with profitabi-

[14] For an unusually comprehensive effort to test the usefulness of sophisticated statistical analyses of innovational processes, see L. Uhlmann (1979). His study covered 218 cases of innovation in 126 firms and concluded that the characteristics of the 'average innovation process' emerging from such statistical evaluations did not in fact describe any of the actual cases . . . and that 'Any theory derived from such a medley of types (of innovations) would refer to an imaginary process of innovation'.

[15] The almost universal acceptance of profitability as a primary determinant of diffusion rates is apparent in any sampling of the literature. For example, see Griliches (1957), Mansfield (1961, 1968, pp. 137 *et seq.*), Rosenberg (1972, 1976, p. 191), Nabseth and Ray (1974, pp. 301–6), Kelly *et al.* (1975, Ch. 4), Boylan (1977, p. 158) and Gold (1977c, p. 180).

lity. Serious analysis of diffusion surely requires digging deeper than to proclaim that purposive organizations are most likely to adopt those innovations which most effectively promote their primary purposes—or that decisions to make substantial commitments are seldom likely to choose recognizedly disadvantageous alternatives.

Rather, the critical question confronting diffusion research derives from the fact that at any given time many (and perhaps most) of those considering a particular innovation decide against adopting it—although all are presumably seeking to improve profitability relative to accompanying risk. Hence, analytical concern needs to be refocused to concentrate instead on probing how such evaluations are arrived at. Even more seriously, it is important to explore the extent to which results represent the rationalization of decisions actually based on less obvious grounds.

The simple fact is that efforts to estimate the profitability of adopting an innovation, especially a major one, usually involve serious difficulties, because of the unavailability of most of the information which would be required, and hence yield results subject to wide margins of error.[16] Such estimates have to encompass the time pattern of changes over the expected life of the innovation in investment requirements, output levels, product prices, input factor quantities and prices, marketing and distribution costs, and taxes. Past experience with economic and market forecasting emphasizes the poor results which have commonly been achieved even in forecasting output and prices at broad aggregative levels, to say nothing of the far greater difficulties involved in making such forecasts for individual plants or even individual projects.[17] And all such uncertainties are in addition to those reviewed earlier as elements of the 'pre-decision environment'.

[16] Such difficulties have commonly been brushed over rather than discussed with care. Exceptions include: Gold (1964a, 1971, pp. 180–2, 1967, 1971, p. 216), Freeman (1973, pp. 231, 252, 1974, pp. 227–38), Mansfield (1973, pp. 218–19, 224–5), Williams (1973, pp. 281–5), Ray (1974, p. 13), Nabseth (1974, pp. 301–6) and Gold *et al.* (1970, 1975b, pp. 142–6). But the seriousness of these difficulties may readily be deduced from the involved and often less than persuasive reasoning offered to justify resort to the particular surrogates employed in place of the profitability specified in the hypotheses ostensibly being tested. Examples include: Mansfield (1961, 1968, p. 143, 1963, 1968, p. 182, 1964, 1968, p. 159) and Nabseth (1973, p. 265). It is also interesting to observe that in Nabseth and Ray's collection of eight industrial diffusion studies (1974) not one provided any direct profitability evaluations by the responding firms. Instead, one provided estimates of pay-back periods (Håkanson, p. 77); another provided estimates of savings in unit production costs for illustrative operations assuming certain batch sizes (Gebhardt and Hatzold, pp. 48–9); and a third provided data on differences in output per employee and in cost proportions between samples of adopters and non-adopters (Lacci *et al.*, pp. 110–12). Still another offered only the author's own 'original ranking of profitability *expectations* to typical plant structures' (emphasis supplied) (Schenk, p. 244). And the only remaining study which offered any quantitative estimate of economic advantage relied on its own estimate of a 'single relative cost coefficient for each production schedule—(i.e. product-mix)—as a measure of the suitability of the shuttleless loom to the individual firm's production'. But, the author notes, 'no cost comparisons between shuttleless and conventional looms in actual operations were provided by any of the respondent firms, nor were they asked for in the questionnaires' (Smith, p. 272).

[17] These are reviewed in Gold (1977b, pp. 51–9).

Reliance on expected increases in profitability as an explanation of adoption decisions and of differences in diffusion rates of technological innovations also involves a conceptual error. In the common circumstances of shifts in technological leadership among competitors, numerous innovations are likely to be developed or adopted not in order to provide additional increments in profitability, but in order to minimize the reductions in profitability and market share caused by the successful pioneering of competitors. And some other innovational adoptions may result from efforts to minimize the effects of developments especially disadvantaging some competitors in respect to the supply and price of inputs or in respect to access to newly developing markets.[18]

Efforts to estimate the prospective risks and other consequences of adopting technological innovations in industry also confront major difficulties. The technological risks of a particular innovation tend to decline, of course, in the later stages of diffusion, as the experiences of an increasing array of prior adopters become available. But this is less true if the rate of improvements continues to be substantial and, in any case, still leaves the risk of superseding innovations becoming available. Much more important, however, are the economic risks to be confronted. These include the possibility of shifts in product-mix that curtail utilization of the innovation as well as the duration of its effective working life. Even more troublesome, however, is the increasing risk faced by later adopters of progressively decreasing benefits as the competitive efforts of earlier adopters tend to pass any cost savings on to purchasers through lower prices and also as any associated wage rate gains come to be enforced on an industry-wide basis. Under the latter conditions, it may become necessary to adopt the innovation anyway, thus bearing its burdens while obtaining little of its benefits.

How then are such decisions arrived at? Because decisions involving commitments for future activities must almost always be made on the basis of serious informational inadequacies and consequent uncertainties, they tend to be based in large measure, as has been discussed at length elsewhere, on the value orientations of influential management personnel, which are rooted in turn on their past training and experience.[19] Indeed, our detailed intraplant studies suggest that a surprisingly high frequency of technological adoption decisions seem to be based essentially on engineering evaluations of expected physical input–output improvements with parallel economic benefits simply being assumed.[20] As might be expected, technologically oriented executives tend to be more responsive to such approaches

[18] For example, see Freeman (1974, pp. 266–7), Gold (1975a, pp. 24–5, 1977c, p. 185).

[19] For an extended discussion, see Gold (1969, 1971, pp. 218–25). Also see Mansfield (1973, pp. 213, 217, 219) and Nabseth and Ray (1974, pp. 12–13, 21, 309–11) and in almost all other chapters, with an especially detailed statistical exploration of such attitudes by Meyer and Herregat (pp. 166–76 *et seq.*).

[20] See Gold (1955, pp. 278–88, 1964a, 1971, pp. 18–01) and Gold *et al.* (1970, 1975b, pp. 144–5).

than those with backgrounds and perspectives oriented primarily to marketing and finance. Hence, managerial attitudes are not merely one of the factors to be included casually along with ostensibly more important quantitative determinants. On the contrary, such subjective judgements probably overshadow the latter in shaping most major capital decisions, although the growing obeisance to seemingly objective decision-making often entails repeated revisions of formal capital budgeting estimates by staff specialists until they accord with the judgement-influenced conclusions of senior management.[21]

Widespread efforts have been made to substitute *ex post* findings and evaluations in place of the basic need for understanding the actual processes of decision-making leading to the adoption or rejection of particular innovations. But the results are unsatisfactory, and may well be misleading, in many (and probably) most cases—especially as the period between the original decision and the time of the research is lengthened. One reason is that hindsight judgements based on actual results necessarily represent different perspectives from the *ex ante* expectations which determined decisions in the face of recognized but unavoidable uncertainties. Favorable results tend to elicit rationalizations stressing the correctness of the earlier analyses underlying the adoption decision, while unfavorable results tend to be explained by emphasizing the effects of uncontrollable external developments. In either case, such *ex post* evaluations are likely to concentrate on the few criteria which seem important at the time of the interview rather than recapturing the multiple pressures and the insecurities at the time of the decision, often because many of the latter have been forgotten.

Another reason for the inadequacy of *ex post* evaluations relates to the factual data often adduced, e.g. ostensible measures of the effects of a given innovation on the costs or profits of the firm. But these obviously need not have any consistent relationship to the *ex ante* expectations underlying the adoption decision for two reasons. First, contrary to common simplistic assumptions, major decisions seldom take the form of climactic once-for-all commitments. Instead, they usually involve successive reviews of past estimates on the basis of developing information and experience and these lead to modifications of expectations and readjustments in still unimplemented commitments. Moreover, major innovations frequently require progressively widening sectors of readjustments in antecedent and later operations in order to regain effective integration of the entire network of processes. Hence, final results are seldom directly comparable with, much less attributable solely to, the initial decision.

Even more important, actual results necessarily reflect the complex, and often inextricable, interactions of the particular innovational effects with numerous other intrafirm policies and activities as well as with a

[21] See Gold (1977b, pp. 57–9).

multiplicity of extrafirm developments.[22] In view of the endless disagreements among R & D, Engineering, Production, Marketing and other groups in taking credit for favorable firm performance and disavowing blame for any unfavorable results, one cannot but be astonished at the naïveté of claims to measuring the specific proportion of profits attributable to innovations which usually affect only narrow segments of total firm operations within a setting involving many other concurrent changes.[23]

In short, in order to develop sounder guides for governmental or other efforts to influence innovational decisions, it seems necessary that research focus more directly on the processes of relevant decision-making as it is taking place, or immediately after its conclusion—i.e. in 'real time'—and that such explorations also seek to analyze the actual quantitative estimates presented for managerial consideration along with the other bases for arriving at such estimates. And additional valuable insights are likely to be achieved by tracing the content of, and the bases for, the succession of later decisions before an innovation achieves effective functioning, and even beyond that as its role comes to be modified by later innovations as well as by changing pressures in factor and product markets.[24]

III. SOME SHORTCOMINGS IN ANALYZING THE EFFECTS OF TECHNOLOGICAL DIFFUSION RELATIVE TO POLICY NEEDS

Interest in research on technological diffusion in industry seems to be dominated by concern with improving private and public policymaking efforts to maximize the net economic and (or) social benefits of diffusion processes. Response to such needs necessitates greater concentration than in the past on determining the effects of technological diffusion. By focusing on rates of diffusion, on differences among such rates and on factors associated with faster and slower rates, much of the published literature has rested on the implicit assumptions that the innovations studied offered significant net economic benefits and, hence, that increasing diffusion rates would be economically (and perhaps socially) desirable.

The vulnerability of such assumptions has been camouflaged to a considerable extent by the unrepresentativeness of most of the innovations studied, usually reflecting hindsight selections of innovations which have already been widely diffused and, hence, presumably found rewarding by many. But such heroic assumptions are clearly open to serious challenge in purportedly general approaches to analyzing diffusion prospects and results. Inasmuch as all innovations obviously involve burdens as well

[22] See Gold (1971, pp. 16–17, 1976b, pp. 2–3, 1977c, pp. 223–5).

[23] This is especially unpersuasive in view of the difficulties admitted by specialists in making effective estimates of the cost savings attributable to individual units of equipment even *ex post*, to say nothing of *ex ante*. See Terborgh (1958, pp. 52, 95–7).

[24] For a remarkable example of such a detailed tracing of major capital decisions involving technological innovations along with the effects of their progressive implementation over an extended period of years, see Skeddle (1977).

as benefits, an understanding of their over-all impacts surely requires identification and assessment of each effect under various conditions before reasonable judgements can be made about the desirability from various points of view of faster or greater diffusion of any given innovation.[25]

A. *On the Structure of Innovational Effects and Their Diffusion*

Studies of the effects of technological innovations are commonly regarded as involving analytical foci quite separate from those around which diffusion studies are centered. It seems clear, however, that appraising the effects of increasing diffusion first requires determination of the effects of adoptions by various types of plants before proceeding to estimate the results of alternative patterns of increasing diffusion, involving the multiplication as well as the interaction of such individual plant effects.

Intraplant and intrafirm effects, which have attracted most attention, should cover much more than the hitherto virtually sole concern with profitability, total unit production costs and/or labor productivity. Other significant considerations include the possible need for changes: in the nature, quality and prices of material, energy, labor and capital inputs; in the scale and flexibility of production; in the quality, mix and prices of products; in labor tasks and associated morale problems; in employee health protection as well as pollution controls. But the beneficial and burdensome effects of changes in these various areas may well differ as among plants with different characteristics, thus tending to yield different results with increasing diffusion depending on which groups of plants predominate.[26]

Increasing diffusion also tends to engender certain effects at the more aggregative level of the relevant industry sector. These might include the intensification of competitive pressures tending, for example, to increase related R & D efforts and to pass along some savings through reduced product prices. On the other hand, they could also encourage joint efforts among competitors to negotiate needed adjustments with trade unions, to overcome pollution and product safety problems and to deal with any governmental restrictions affecting utilization of the innovation. And still another set of effects at the industry level might involve changes in concentration, in entry barriers, in international competitiveness and in competitiveness with other industrial sectors producing substitute products.

Still wider ramifications of the increasing diffusion of technological innovations in industry would certainly include backward pressures from

[25] Cf. Gold (1977c, pp. 185–6) and Williams (1973, p. xvii). For interesting surveys of the perceptions of actual and prospective adopters, see Lacci *et al.* (1974, pp. 134–5) and Smith (1974, pp. 268–71).

[26] An analytical framework for exploring such dimensions of technological effects was presented in Gold (1955, pp. 169–232) and has been more fully developed in Gold (1977c, pp. 197–228).

adopters on the providers of needed inputs, including suppliers of raw materials, energy and fabricated components as well as capital facilities and funds.[27] Associated pressures on trade unions might include changes in employment levels, skill requirements, flexibility in work assignments and bases for payment differentials. And another stream of pressures tends to be generated in the direction of customers, who now face the opportunity, or need, to adjust to changes in product capabilities and perhaps prices by altering their own production processes and even products.

Finally, effective analysis of the still further impacts of increasing diffusion might include effects on the communities (and regions) in which adopting and non-adopting plants are located, i.e. on employment, income and investment as well as on pollution and safety hazards. Such broader effects would also encompass resulting impacts on natural resources and energy requirements, on imports and even on defense in some cases.

B. *On the Measurement of Innovational Effects*

Determination of the prospective effects of available innovations is obviously important both in deciding whether firms adopt or reject them and also in broader evaluations of the desirability of faster or greater diffusion. Aside from occasional strained efforts to assess their potential effects on profitability, most attempts to measure innovational effects have focused on changes in physical input and physical output quantities, in related input–output relationships, and in total unit costs (or particular components of them). Most such measures are clearly erroneous, however, and may be grossly misleading because they tend to ignore, or give only peripheral attention to, accompanying innovation-induced changes in the qualitative characteristics of the inputs and outputs affected.[28]

Specifically, evaluative efforts in this area commonly involve deflating changes in the value of products by changes in the average price of products to measure changes in physical output; and similarly deflating changes in the cost of materials, labor and capital goods by changes in the average price of each of these input categories to determine changes in their respective physical input levels. Such expedients obviously imply that only the quantities of products and inputs have changed, leaving their qualitative characteristics essentially unchanged. But virtually all major technological innovations violate such assumptions. Most require changes in the kinds and specific physical or chemical characteristics of at least some purchased materials and in the functional capabilities of capital goods, and sometimes

[27] Successively broader models encompassing such further effects of technological innovations were presented in Gold (1964a, 1971, pp. 198–9, 1977c, pp. 220–7, 1978). The latter also includes preliminary explorations of the broader ramifications of two sets of major technological innovations.

[28] Such problems are discussed in some detail with specific reference to their implications for measuring the effects of technological innovations in Gold (1973, 1975b, pp. 25–39, 1978).

in the composition of required labor skills. And most also lead to, or necessitate, changes in the service attributes of at least some products as well as in the product-mix. Clearly, the more numerous and significant such alterations in the qualitative characteristics of inputs and outputs, the wider are likely to be the margins of error of the traditional measures of the productivity and cost effects of technological innovations.

Resulting changes in the qualitative attributes of products, however, often provide opportunities for purchasers engaged in further processing and fabrication operations to achieve new competitive advantages. Such effects would tend to encourage diffusion of the original innovation through additional pressures for adoption from customers of the plants considering such decisions. Similarly, innovation-induced changes in the needed qualitative characteristics of materials and capital inputs might trigger adaptive adjustments and developments by suppliers resulting in improvements available not only to the firms which have already adopted the original innovation but to laggards as well. As a result, the latter's evaluation of the net advantages of adopting the original innovation would be raised, thereby tending to increase the number of adoptions.

In short, perceptive analysis of the economic effects of technological innovations requires abandoning continued reliance on the crude measures developed during the many decades when the theoretical framework of economic analysis explicitly excluded such phenomena. More effective measurements require confronting the problems of adjusting quantity and price changes for concomitant changes in the qualitative characteristics of inputs and outputs which are a major reflection of technological effects. It should be recognized, however, that such efforts reinforce the earlier-mentioned need for acquiring sufficiently detailed knowledge of the technologies involved to be able to identify the kinds of qualitative changes which have an important bearing on economic effects and to try to assess the nature and magnitude of such effects.

IV. CONCLUDING OBSERVATIONS

The preceding broad analytical framework has been presented in order to emphasize the wide range of possible effects to be considered and the variety of viewpoints from which evaluations may be made of the desirability of broader or faster diffusion of any technological innovation in industry. It seems reasonable to argue that industrial managements, government agencies and academic scholars would all benefit from the development of progressively more effective bases for systematic examination and appraisal of the effects of technological innovations as well as of different patterns, rates and levels of diffusion. Results to date have not been of much practical value to industrial managements, partly because decision-making responsibilities tend to limit their interest to findings more directly relevant to their own immediate needs, but in even greater measure because industrial specialists are usually far better informed than transient researchers from outside the industry about the diffusion patterns of relevant technological innovations and the factors influencing them. Nor have the results of research in this area offered much useful guidance to government policy making because of the recognized vulnerability of attempts to generalize from findings commonly based on patently inadequate samples and obviously inadequate penetration of the complex considerations underlying the actual decisions reflected by diffusion rates.

Perhaps more disturbing from the standpoint of responsible scholarship has been the readiness of some researchers to criticize industrial managements for delays in adopting seemingly relevant technological innovations. Most such attacks have been based on arguable inferences from data providing hindsight perspectives or comparisons with experience in other countries. But such judgements reflect ignorance of, or disinterest in, the specialized limitations of the given state of the innovation relative to the dominant needs of prospective adopters in earlier periods. Surely, serious analysts cannot assume away the difficulties of scaling up innovations or adapting them to wider areas of application;[29] nor should they deny the possibility that shifts in factor prices can appropriately alter prior evaluations of innovational effects, or that earlier commitments of available resources to needs deemed more urgent represent rational reasons for deferring adoption of an innovation.

Indeed, it is of fundamental importance to recognize that virtually all innovations involve technological and economic risks at all stages of diffusion and that decisions to reject may accordingly be entirely justifiable at any stage by some prospective adopters. The fact that most innovations fail to achieve widespread diffusion testifies to the pervasiveness of such risks and the need for evaluating them carefully. It is surely irresponsible in considerable measure, therefore, to launch such criticisms from the safety of hindsight prospectives. Oddly enough, even such *ex post* attacks are seldom buttressed with serious evidence of the economic superiority of the innovations at earlier periods, reliance being placed rather on estimates based

[29] For example, see Adams and Dirlam (1966, pp. 167–89) and Ault (1973, pp. 89–97). The findings in the former may be compared with the contrasting results in the other studies cited in footnote 11 above and the findings by Ault may be compared with those of Rosegger (1979). Incidentally, it is curious that Adams and Dirlam as economists urging more rational decision-making by industrial managers fail to discuss the less favorable profit performance of the steel companies which they praise as technological pioneers as compared with those criticized as laggards. This is not at all intended to suggest that the profitability of large firms is an effective measure of the distinctive effects of technological innovations affecting certain component operations. But it does suggest bearing in mind that the managements of such firms are compelled to use an evaluative framework covering a far larger array of alternatives than are likely to be of concern to scholars analyzing any given narrow sector of decisions, such as the timing of adoptions of particular innovations. Indeed, such actual profit results may even suggest that the delayed adoption of certain technological innovations did not have a deleterious effect on the performance of the larger companies criticized for such delay.

on highly over-simplified assumptions which clearly disagree with the contemporary evaluations of industry specialists. Accordingly, it would be more in accord with scholarly objectives to try to understand why decisions were made which do not conform to the analyst's expectations than to imply that such decisions were attributable to the sloth, stupidity or ignorance of substantial sectors of industrial management.

In order to further such needed understanding of the factors affecting technological diffusion processes in industry, it would seem desirable that future diffusion research concentrate more sharply on:

1. identifying the effects of successive improvements on the technological capabilities and limitations of particular innovations;
2. estimating resulting changes in the number and characteristics of active adoption prospects;
3. exploring the evaluation processes of individual firms which underlie adoption decisions, including the pre-decision determinants of the relevance of any given innovation as well as the bases for estimating its prospective technological and economic contributions to the future performance of the firm;
4. analyzing the economic and social effects of increasing diffusion of the innovation on the growth and competitive strength of the industry, on its internal competitiveness, on the industries supplying its inputs and those purchasing its products, on the communities and regions in which the industry is located, and on other performance criteria of concern to government agencies, trade unions and consumers; and
5. evaluating the resulting advantages and disadvantages, from the standpoint of various interests, of increasing or decreasing the rate of diffusion of the innovation at various stages of its development.

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