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Source: *Economic Geography*, Jul., 1975, Vol. 51, No. 3, Studies in Spatial Diffusion Processes: II. Conceptual (Jul., 1975), pp. 231-251

Published by: Taylor & Francis, Ltd.

Stable URL: https://www.jstor.org/stable/143119

PERFECTIVES ON TECHNOLOGICAL CHANGE AND THE PROCESS OF DIFFUSION IN THE MANUFACTURING SECTOR*

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Interest in technological change arises out of a search for answers to such comprehensive questions as to how and why manufacturing industries come into being, grow, and decline at various rates. What are the processes involved? What are the reasons for the establishment and growth patterns of plants and industries in specific parts of geographic space?

Anyone who has been engaged in such search appreciates the significance of technological change in its influence upon the birth and death of plants, firms, and industries, and upon the viability of plants and industries in specific locations. A knowledge of the nature of the influences of technological change and its relationships to other explanatory variables provides the information and insights we need for a better understanding of the role of technological change in a multiplicity of processes—social change, industrial growth, and structural change—and in the locational arrangements and behavior of plants, firms, and industries.

A review of the literature reveals an increased interest in technological change during the last decade. But despite the availability of many excellent conceptual and empirical studies, researchers note a continuing shortage of information on critical dimensions of technological change and related diffusion processes in manufacturing. For instance, there is a recognized need for greater knowledge of the *process* of technological change. This in turn requires much further study of the role of research and development in the discovery of inventions and in the processes leading up to the act of innovation. In particular, a far better understanding is needed of the multiplicity of factors influencing the favorability and unfavorability of the decision to innovate and the subsequent economic success of innovation. Some researchers have noted that invention and innovation patterns are markedly different in some industries as compared to others. Why is this so? Another major dimension of technological change in manufacturing about which knowledge and understanding is lacking is the process of the diffusion of innovations. Relatively little is known about the various factors which influence the rate of diffusion, and the way in which such innovations spread through the industrial structural fabric of the manufacturing sector.

Mansfield and others have noted considerable need to achieve a greater un-

* The authors wish to thank William Beyers, Rodney Erickson, John Griffiths, Peter Harrison, and Gunter Krumme for their perceptive comments and helpful suggestions on an earlier draft of this paper. We also wish to acknowledge the support of the National Science Foundation.

derstanding of the role played by technological change in the process of economic growth and productivity increase [*24*; *43*; *54*; *55*; *74*]. An evaluation of this role requires further research on the problems of measuring technological change in different settings. In this regard, for example, how would one assess the qualitative and quantitative contribution of technological change to the pattern of regional economic growth and firm and industry productivity change in a region such as the Pacific Northwest during the last decade?

Many economists and geographers believe that the inadequate understanding of the processes associated with the diffusion of technology originates in great measure from a lack of systematic micro-level empirical studies focused on the transfer of specific technologies in specific industries. Additionally, such studies should also be carried out at various geographical scales, plant, industry, and multi-industry levels, as well as from the perspective of the firm.

An important ingredient in providing insights into the nature and implications of technological change and innovation diffusion in the manufacturing sector is the guidance derived from already articulated explanatory frameworks. Unfortunately, an inspection of the literature indicates that there are very few such conceptual frameworks [*37*; *81*].

In this paper, therefore, we propose to make a contribution to the development and specification of conceptual frameworks that will provide a better understanding of the mechanism of technological change within the manufacturing sector and aid in the identification of the nature and significance of the major explanatory variables. We are especially concerned with revealing and evaluating the dynamic nature of these variables and their relationships in the ever-changing technologies of firms and industries in various regions of the world. To carry out such a task we shall first discuss briefly some of the characteristics and attributes of technological change in the manufacturing sector, then examine the processes associated with the diffusion of innovations and adoptions from a number of perspectives. We shall define at the outset the relevant concepts that form the basis of later discussion. Rather than focusing primarily on the spatial component of diffusion processes as is customary in the geographical literature, we shall be concerned with identifying those key elements and their interrelationships that are the substance of the technological diffusion process in manufacturing. We believe that an appreciation of the nature and significance of these elements and their relationships will facilitate more adequate study and evaluation of the spatial and economic dimensions of technological change.

DEFINITIONS

A study of the term *technological change* reveals that it is an exceedingly elusive and complex concept. In fact, a few years ago Schmookler noted that it was the *terra incognita* of modern economics [75]. This also appears to be the case in geography and other disciplines. One is not surprised, therefore, that there are a number of different definitions of the concept of technological change.

Schmookler's definition of technology provides a useful introduction. He regards technology as:

> The social pool of the industrial arts. . . . The rate at which new technology is produced in any period is the rate of technological progress. . . . When an enterprise produces a good or service or uses a method or input that is new to it, it makes a technological change. The first enterprise to make a given technical change is an innovator. Its action is innovation. Another enterprise making the same technical change later is presumably an imitator and its action imitation [75, p. 2].

Other authors have highlighted the multidimensional nature of technological change. Some stress the diverse forces of threat and challenge which are often concomitantly associated with the process [9]. A number of researchers have focused attention on the dynamism reflected in the chain reaction effects of technological changes as manifested not only in firms and industries but also in the social transformation of societies [*8*; *58*; *78*].

The characteristics of society's pool of knowledge regarding the industrial arts strongly influence society's stock and flow of *inventions*. Inventions are prescriptions for new products or processes that were not obvious to those skilled in the relevant industrial arts at the time the various ideas were generated. Inventions can occur in many ways, chance often playing an important role, and they can result from the efforts of independent inventors as well as corporate research laboratories [55].

Inventions need not result from scientific advances, although they frequently do, and inventions can occur in either the research or the development phase of organized or unorganized research and development activity. Chance and deliberate intent play their respective dynamic roles in the generation of inventions and, consequently, the process of invention is inherently difficult "to analyze, map out, organize, and direct" [*55*, p. 11].

Mansfield states that when an invention is applied for the first time it is called an *innovation* [55]. Schmookler defines innovation as the *action* taken by the first enterprise to make a given technical change. By taking such an action the enterprise (representing its decision makers) becomes an innovator [75]. The utilization of an invention thus represents "a key stage in the process leading to the full evaluation and utilization of an invention" [*53*, p. 99]. Economists have traditionally stressed that it is the decision by the enterprise to use an invention that endows the invention with economic significance. However, the distinction between inventor and innovator is not always clear-cut, for the *same* person or enterprise may serve in *both* capacities [*42*; *86*]. Such is frequently the case in large corporations which have major research and development components. Furthermore, individual inventors or enterprises may not want or always be able to function as innovators.

The time interval between an invention and its eventual utilization as an innovation is often long, but displays considerable variation; for example, seventy-nine years for the fluorescent lamp and one year for Freon refrigerators [*25*; *27*]. Very few inventions become innovations, and only a small number of innovations become commercially successful. Increasingly, evidence suggests that for major innovations the particular time period from basic discovery and the establishing of technological feasibility to commercial application is shorter now than during the early part of this century. This period of time also appears to be shorter in the case of innovations which have consumer as compared to industrial market application. Interestingly, federal government agencies take less time than private industry to apply inventions commercially [*50*]. Relatively long time lags may also characterize the diffusion of specific innovations. Again our information base is inadequate. Nevertheless, available evidence suggests that on the average the process takes many years rather than many months or weeks [*55*; *74*].

Unfortunately, the above definitions and the logic of the functional connections between them create an illusion of clear-cut distinction between innovation on the one hand and imitation or widespread adoption on the other. Such a distinction would assume that the imitation would exactly replicate the innovation. This is an unlikely event in the manufacturing sector. For example, it would not be sufficient to replicate exactly the new good, service, method, or input. An enterprise would also need to replicate exactly the total internal and external environment of the enterprise which made the innovation. Differences in the various environments of enterprises necessitate that adaptations be carried out by imitators or adopters. In some industries, an imitation would have to improve upon the original innovation if it were to stand a chance of being commercially successful. The extent and nature of these adaptations result in our asking how valid is the customary distinction between innovation and imitation or adoption?

Even though the diffusion process begins once the invention is first introduced by the individual or enterprise, we are concerned with the process of diffusion and learning which follows the initial act of innovation. This innovation as mentioned earlier may take the form of a new good or service or the use of a new method or input. Following Schmookler's reasoning, it can be argued that another enterprise subsequently making the same technical change is defined as an imitator and its action is imitation. Thus, the diffusion of a new technology of innovation over time and geographic space would be defined as the process of imitation or adoption of an innovation by potential users, for example, hybrid corn [*11*; *12*; *17*; *32*].

The term *transfer of technology* which has been used by a number of researchers sidesteps this distinction. Gruber and Marquis state that the transfer of technology is "the utilization of an existing technique in an instance where it had not previously been used. This can be merely acceptance by a user of a practice common elsewhere, or it may be a different application of a given technique designed originally for another use" [*35*, pp. 255-56]. It is desirable to view the process of the transfer of technology within a much broader institutional framework as expressed by Doctors: transfer of technology is a "process whereby technical information originating in one institutional setting is adapted for use in another institutional setting . . . transfer . . . implies the adaptation of new technology through a creative transformation and application to a different end use" [*23*, p. 3].

Such definitions of the transfer of technology would seem to be in harmony with the transfer of innovations providing we use Roger's definition of an innovation. He suggested that an innovation is "an idea perceived as new by the individual. It really matters little, as far as human behavior is concerned, whether or not an idea is 'objectively' new as measured by amount of time elapsed since its first use of discovery. It is the newness of the idea to the individual that determines his reaction to it . . ." [*71*, p. 13].

TECHNOLOGICAL CHANGE AND THE MANUFACTURING SECTOR

We now examine some aspects of technological change within the manufacturing sector from two perspectives, namely, the sectoral and organizational. Conventionally, an industry is designated on the basis of technological characteristics, for example, standard industrial classification schemes. While the limitations of this type of schema are well known, it is important to examine initially technological change from a sectoral perspective, the traditional frame of reference used by most researchers. A different perspective of technological change can be gained in the contrast, by emphasizing the functional and behavioral relationships of various business environments. These considerations are taken up in the section on organizational perspective. One must caution that the use of such an approach has the effect of bringing some elements into sharper focus and submerging or even eliminating other elements.

SECTORAL PERSPECTIVE

In manufacturing, the sectoral perspective of studying technological change at plant, firm, industry, and multi-industry levels has been primarily conducted within a neoclassical economic framework. Here concern is with articulating the role of technological change in the development of various patterns of economic growth and structural change within the manufacturing sector or its component industries.

Technological change is analyzed by most economic theorists within a long-run equilibrium framework. However, some economists such as Salter have expressed dissatisfaction with the use of such a framework for studying a complex phenomenon like technological change [*74*]. It may well be that our focus should be on tendencies toward disequilibrium rather than on tendencies toward equilibrium. Most western economists assume that the economic system within which technological change is examined is some form of competitive system. Most growth and technological change theorists assume that the system operates under conditions of imperfect competition [*13*; *53*; *56*; *65*]. This appears to be a realistic assumption with respect to most manufacturing industries. The assumed nature of the economic system within which we study technological change in the manufacturing sector is also a fundamental consideration. The nature of the economic system affects our expectations of how plants, firms, and industries operate under different economic conditions given specific objective functions.

On the conventional assumption that the economic decision makers or actors in the system are attempting to maximize goals such as profits or earnings, one would expect innovators to flourish and innovations to spread. Innovations which represent technological progress in the form of new processes and managerial and organizational changes and some new products can favorably influence productivity. The contribution by innovations to a rise in productivity represents a positive contribution to the economic efficiency of the affected plants, firms, and industries. Such a contribution is manifested in a downward movement of the relevant unit cost curve. Given appropriate price elasticities for their products, these plants and industries tend to be in a position to expand output. One assumes that the profit and growth goals of the affected plants would be a strong influence on the levels of output in these plants and industries. Implicit in the above discussion is the assumption that innovators and subsequent adopters of innovations enhance their competitive position by way of cost reductions [*88*; *89*].

Product innovations form the basis for the establishment of new industries which, in turn, provide the potential for changes in the industrial compositions and even net expansion of the economic system. These innovations are associated with changing consumer and industrial requirements. They frequently represent competitive substitutes for existing and new products. New product industries serve as potential sources of profits or the means of satisfying other economic aspirations of decision makers within the system. We shall examine some of the broad incentives for innovation and adoption within the manufacturing sector.

Research and Development. There are ample theoretical and applied grounds for undertaking a search for a better understanding of the factors behind successful innovation. In the contemporary world the belief prevails, on the part of governments and many private firms, that the deliberate investment of funds in R and D is both necessary and desirable if they are to be innovators and successful adopters. R and D statistics are often regarded as an indication of the intensity of the search for innovations.

Government sponsored studies reveal that mission-oriented research has been successful in terms of resultant innovations [*62*]. However, cost consciousness was not as apparent in these programs as it would be in the development of innovations for the commercial market [93].

Unfortunately, there is little accurate information on the number and economic significance of innovations derived from sources other than government and private industry R and D programs. What kinds of innovations are R and D investors seeking, and in which industries are investments made? At a more microlevel we should know what associations exist between the innovativeness of different size firms within an industry. Some authors suggest that small firms specialize to a higher degree than their larger counterparts in an industry [*4*; *24*; *40*]. Furthermore, the emphasis on returns from R and D investment overlooks the fact that a firm may accept the *supply* of inventions and innovations as given, and attempt to maximize its access to available inventions and innovations. Responses to this situation include counterpunching firms, innovation imitation, intelligence networks, and the advent of roving technical scouts [*49*; *77*; *78*].

Documented evidence provides some insights into the main purpose of industrial R and D investment. New product development and improving new products are generally more important than investment in new production processes [*47*; *62*]. The relative figures appear to vary according to whether the region or country is importing new technology or is developing it indigenously.

In the United States there is considerable variation from industry to industry in R and D investment and in the intensity of search for innovations, as reflected in R and D expenditures as a percentage of sales in various industries [*63*, p. 25]. However, there is a correspondence between research intensity of industry groups and the output of new products. In addition, in 1971 five industries—aircraft and missiles, electrical equipment and communication, chemicals and allied products, machinery, and motor vehicles —accounted for more than 80 percent of the $18.4 billion of R and D funds in the United States [*63*].

In evaluating the impact of R and D expenditures on the creation of innovations, we must consider both direct and indirect effects. Not only must we be aware of the innovations created directly in the industries in which the R and D expenditures were made, but we must also realize that these innovations, in the form of inputs used by other industries, lead to the creation of second-order or secondary innovations and spin-offs in these recipient industries [*8*; *18*; *19*; *22*; *26*; *31*; *95*]. Documented examples of such interindustry transfers of technology are chemicals in the veneer and plywood industry [*48*], chemicals in textiles [*42*], and computers and control systems in many manufacturing industries [*55*].

The Firm and Innovation. While research on certain kinds of innovation has been carried out at the firm level, it is not always clear whether the plants examined belong to single or multiplant firms, or whether the plants are single or multi-industry firms. Research at the firm level also tends to be focused on "technological" innovations. These are usually innovations which *embody* new technology by introducing technological changes into the production process [*13*; *43*; *74*; *82*]. In contrast, much less attention has been given in the literature to the nature and role of managerial and organizational changes, or what are called *disembodied* innovations at both micro and macrolevels of analysis. Technological improvements of the disembodied kind, when introduced, have the effect of altering the production function. Significantly, it has been observed that gross investment is not required to carry out this kind of innovation [*13*, p. 77]. However, recent empirical evidence suggests that the subject of disembodied innovations merits much greater attention [*48*, pp. 216–25].

One topic which has been recently investigated is the effect of the firm size on technological innovation [*63*, pp. 34–52]. The rather limited studies of firms in comparatively few and perhaps non-representative industries offer a number of tentative conclusions: (1) independent inventors and small firms are prominent contributors to technological innovation [*25*; *45*; *64*]; (2) large size is not necessary for innovation [*18*; *60*]; (3) larger firms utilize innovations faster than small firms [52]; (4) the importance of large firms in innovation is increasing over time [52]; (5) a few large firms account for a large percentage of R and D expenditures [*28*]; and (6) larger firms have a foreign trade advantage in manufactured products [*36*].

Some elaboration on these findings is necessary. For example, it is not always possible to delineate clearly what is meant by large, medium, and small firms. It is also difficult to ascertain whether or not R and D productivity is greater in large firms. Does productivity increase the amount spent on R and D? Empirical evidence on these aspects is very limited. A seminal study by Mansfield of the iron and steel, petroleum refining, and bituminous coal industries does, however, suggest that

> (1) there is a close relationship over the long run between the amount a firm spends on research and development and the total number of important inventions it produces; (2) in two out of the three industries examined (petroleum and steel), the results did not indicate any marked advantage of very large-scale research activities over medium-sized and large ones; and (3) the evidence available suggests that the productivity of a research and development effort of given scale is lower in the largest firm than in the medium-size and large ones [53, p. 199].

Mansfield's tentative conclusions highlight the need for additional studies of the economic efficiency of investment in R and D, and the processes determining future patterns of technology. These patterns, in turn, will profoundly affect the nature and direction of economic growth in an economy by bringing about changes in productivity trends in plants and industries.

It would be of value to learn the nature of the relationship between such investments in R and D and the number of commercially successful innovations and adoptions made by firms of different sizes found in different industries. Many authors have underscored the importance of viewing patterns of R and D within a temporal context, reflecting the belief that R and D investment and effort contain an important *learning component*. Do firms take into account their past R and D activities when programming and allocating current R and D investments directed toward innovation and adoption? Recent studies have partially explored the nature and significance of the "learning curve" as a behavioral explanatory concept in theories of economic growth and technological change [*5*; *6*].

Product Cycles and Market Expansion. A less behavioral explanatory concept that has received attention during the last decade has been the product cycle (a single-product industry or firm expansion curve) [*19*; *90*; *94*]. It is hypothesized that different stages of single-product industry expansion curves are associated with different rates of innovations [*41*; *90*]. In the early phases of the product cycle when production technology is less stable, innovations are more numerous and frequent. As the rate of expansion of the product declines, production technology also stabilizes and innovations are fewer in number. Empirical studies on various kinds of industries provide some credence to these hypothesized relations between the product cycle and innovations [*94*]. These relationships merit further examination in a wider range of manufacturing industries.

Some measure of the intraindustry and interindustry economic significance of innovations generated at different stages in the product cycle would be helpful.

There may be many innovations associated with numerous production functions in existence at the beginning of the product cycle. Individually, these may be of little economic significance in terms of their impact on output growth and the commercial viability of the product. During later stages fewer innovations occur, but some of these may have major intraindustry and interindustry economic and commercial implications. Studies of this kind should provide insights concerning a firm's "propensity to innovate" during various stages in its industry's product cycle [29]. Since most firms are multiproduct firms, many measurement and analytical problems would be encountered in testing these hypotheses.

The form of the product cycle for a domestic industry in a particular country or region can be affected by varying the rate of its output over time. The industry's market can be expanded markedly in a short period of time, by the opening up of overseas or regional markets, for example. The domestic industry may then be able to increase its rate of growth and even offset a previous relative or absolute decline in its output. The relationships between market size and economies of growth are fairly well known. However, it would be interesting to probe further the nature and implications of relationships which exist between market size changes and innovation within a product cycle context. Gross investment tends to be higher in fast-growing industries. Let us assume that new export markets contribute to a marked increase in the rate of growth of a particular industry. Would such a rapid expansion of output provide the motive for an increase in the rate of disembodied technological change in the form of better organization and management practices? Would increased investment accompanying the domestic or regional industry's rapid expansion of output reflect an increase in its rate of embodied technological change, and represent process rather than product type innovations? To what extent would the increase in industry's replacement and new investment reflect adoption rather than innovation? Scale changes in an industry would also tend to generate inducements for technological changes in linked industries. Studies on this topic should also be carried out at the level of the firm for both academic and policy formulation purposes.

ORGANIZATIONAL PERSPECTIVE

Frequently we have used the term "firm" in our discussion of technological change in a general sense of denoting the firm as an "organization" carrying on a host of economic activities within an economic system. This viewpoint stems from the belief that organization and associated management practices are crucial explanatory variables. The recognition and use of this more behavioral concept of the firm help to reveal new insights about technological change and provide a basis for conceptually analyzing related diffusion processes.

Entrepreneurs. Some authors believe that there is value in investigating innovators as well as innovations [*34*; *38*; *76*; *86*; *96*]. Do innovators have different human qualities from noninnovators? How are these qualities summed up in the term "enterprise"? What combination of qualities qualify a person as an entrepreneur who performs such a crucial role in effecting technological change in Schumpeter's economic growth theory [*79*]? Do entrepreneurs require different combinations of human qualities to be successful in different industries?

The role and relevance of the entrepreneur has not gone unquestioned. Galbraith questions the relevance of the entrepreneur-owner in modern firms and corporations [*28*]. Galbraith argues that firms controlled and operated by a single entrepreneur or decision maker are far less significant in the economy than those firms which are operated by a salaried board of directors, acting on behalf of stockholders. He divides firms or corporations into entrepreneurial and mature corporations. In entrepreneurial firms, the individual who has control of capital is still accorded power, and the age, size, and simplicity of operation of the firm explains why he continues to hold such power. In mature corporations, the leadership or directive force is vested in the management—a relatively small group of senior officials. However, Galbraith states that the real power of the mature corporation rests with the technostructure. This is a large and composite group of individuals extending from the most senior officials of the corporation to its white-collar and blue-collar workers. The totality of the technostructure contributes information to group decisions. In Galbraith's opinion, the technostructure and not management "is the guiding intelligence—the brain—of the modern enterprise" [*28*, p. 71]. Many business economists, however, believe that management represents the brain of the corporation [*56*; *85*].

Organization Structures. In recent years, many studies have attempted to relate organization structure to performance [*20*; *97*]. However, it is very difficult to establish and quantify such a relationship, as performance is the product of the interaction of many dynamic factors.

> Firms make tradeoffs between risk and profit, between growth now and growth later on. Besides, even if one could decide how best to measure performance, one could never be sure that the results were influenced by the choice of structure. . . . Differences in reporting and accounting practices add further problems to the comparison of performance in different firms. For example, different accounting treatments of certain expenses, such as R and D, affect both the reported net income and the yield on investment [*85*, p. 79].

These caveats notwithstanding, we believe that the changing organizational structure and associated systems of management of firms represent important disembodied technological changes and are therefore worthy of study from such a standpoint [*68*].

The Harvard Mutinational Enterprise Project has developed a set of macrodescriptive models of firm growth which would be useful for investigating various aspects of disembodied technological change [*80*]. This set, largely influenced by Chandler's earlier work, focuses on organization in relation to corporate growth [*16*]. Case studies, primarily in manufacturing firms in the United States and abroad, suggest certain uniformities in the relationship between corporate development strategy and corporate organization structure [*16*; *73*; *80*].

In essence, the design of a firm's organization reveals how the firm is administered presumably so as to be in harmony with its strategy. The latter has been defined as "the determination of long-term goals and objectives of an enterprise, and the adoption of courses of action and the allocation of resources necessary for carrying out these goals" [*16*, p. 16].

In modeling corporate development, it is assumed that not only are there meaningful stages along a continuous path, but that there are also uniformities in the relationship between stages. Each stage is defined in terms of five characteristics, which may be identified empirically and quantified to a degree: (1) managerial structure; (2) pattern of internal-external transactions (primarily product transactions); (3) key concepts of resource allocation; (4) measures of performance; and (5) rewards and punishments [*80*, p. 6].

Firms in Stage I are "usually small enough to be administered by a single man, typically the owner and founder" [*85*, p. 11]. These firms seem to be similar to Galbraith's entrepreneurial corporations. When the firm establishes "functional departments such as sales, production and finance, each headed by a company officer reporting to the president, it has reached Stage II. Firms in this stage frequently have only a single line of products and maintain to some degree the stability of these activities" [85, p. 14].

This is followed by Stage III firms that use a divisional organizational structure based usually on product or area lines and as such operate as quasi-firms. The operating responsibility for production and marketing for each division is vested in a general manager who in turn is responsible through the corporate staff to the president of the firm. In Stage III, corporate staff has operating responsibility for finance, control, and so forth for the whole firm. Foreign subsidiaries tend to be managed in a foreign division. The growing importance and complexities of dealing with multinational manufacturing activities led in the 1960s to the development of a global organizational structure which is found in Stage IV firms. This global structure replaced the international divisions of many firms and has taken several forms:

> Some firms, like Ohlin-Mathieson, based their structure on product considerations and assigned worldwide responsibilities to the erstwhile domestic product divisions. Others, such as Corn Products, divided their organization into area divisions, each responsible for one geographical region of the world market. Still others like AMF Corporation, chose a combination of both product and area assignments in a mixed structure [85, p. 26].

Many firms have found all three global organizational structures to be unsatisfactory, and there will undoubtedly be further organizational innovations to facilitate the attainment of affirmed corporate goals.

Stopford and Wells' study of some 136 domestic and multinational firms classified by organizational structure suggests that Stage III firms were more successful than those in Stage II [85, p. 83]. Their published data contradict the predictions of some economists that diseconomies of scale will lead to declining profitability as firms grow large. The Stage III firms seem to offset or moderate the effect of scale diseconomies by diversification, which in effect divides the enterprise into smaller business units. They also spread research costs over larger sales volumes. The decoupling of the organizational structure by Stage III firms seems to allow rapid growth without an even faster increase in overhead costs. Disembodied technological change appears to play a significant role in the relative performance of firms with different organizational structures as measured by rate of return on investment and growth of sales. The strong connections between firm organization and its management were stressed in this study. The above authors also emphasized the fact that the *quality* of the various managers within these hierarchical systems was crucial. Management reduces the number of communications channels and in a coordinating role contributes critically to the efficiency of communicating information through the system. We believe that the organizational structure of firms merits further study within the context of an examination of technological change in manufacturing.

Risk and Uncertainty. Another topic of considerable contemporary interest is the question of the suitability of the organizational structure of the "modern" corporation to deal with uncertainty. Writers such as Schon conclude that the multiplant corporation is suitably designed to deal with risk but not to deal with uncertainty [78]. Innovation always contains an element of uncertainty since no matter how well the research and development staff have performed their various tasks, there is always doubt as to how suitable the corporation's organizational structure is for dealing with the process of innovation. Is it as flexible as it could or should be to deal with uncertainty in invention and innovation? "Mature" firms are felt to operate best under stable conditions or where available information enables the firm to estimate the risks associated with any action it undertakes [*78*, p. 65]. This is essential for complex planning and control purposes, and planning and control are hallmarks of the modern corporation.

It is also instructive to view the firm as a social system [*84*]. Within the larger firms especially, there are many persons who contribute to the decision to innovate or adopt. These people do not necessarily view the innovation and its subsequent repercussions on the firm and their own objectives in the same way. One may then expect to find resisters and promoters within the decision-making system [*2*; *14*; *76*; *77*]. These individuals with their different perceptions and their different views concerning the efficacy of the decision to innovate or adopt will in various ways affect the processes of conversion of an invention to innovation, and innovation to an adoption or imitation [*1*]. In addition, certain senior officials are often identified as key promoters or key resisters during the period before the final innovation decision is made [*3*; *66*; *76*].

Furthermore, it is of interest to know whether the smaller entrepreneurial firms can cope with uncertainty better than the corporate firms. One entrepreneur may well be able, in general, to make a decisive decision more quickly than a group of individuals, but this will not guarantee that it is a successful decision.

THE DIFFUSION PROCESS

In our discussion of technological change in manufacturing from the sectoral and firm perspectives, attention was focused on aspects relating to the process of innovation. However, the distinction between an innovation and an adoption is especially difficult and frequently inappropriate when we examine the diffusion process. In this section of the paper, therefore, we will distinguish between the "decision to innovate" and the "decision to adopt" only when conceptual benefits and insights may be gained. We now examine a number of perspectives for the study of the process of diffusion of technology in the manufacturing sector.

TECHNOLOGICAL GAPS

Some researchers review the diffusion process within a technological gap context [*74*; *83*; *84*; *87*]. The framework of analysis is based on a belief that at a point in time any body of technological knowledge is capable of utilization within an existing economic system. At that same point in time in an economic system, specific commercial use is made of this body of knowledge. When the actual use is not equal to the potential use at that time, a technological gap exists and the economic system is not as efficient as it could be. When viewed in a temporal and spatial framework, potential and actual technologies change sequentially and cross-sectionally over time and space as do the economic and other values which determine the nature of the economic systems within which the technological gaps are measured.

In western economies, each of the three systems—firms in the private sector, government, and individuals—has technological gaps which presumably differ in magnitude, nature, and significance. The closing of such a gap implies a potential for increased economic efficiency in all three and for increased profitability and growth in the private sector. Governments may view the closure as signifying a more effective use of scarce resources, a way of stimulating the growth of their industries, and as a means of becoming more internationally competitive. Individuals may perceive the closure of the technological gap as critical to consumption levels and quality of life.

In the manufacturing sector so-called best-practice firms represent surrogates for what is technologically possible in various industries [*48*; *74*; *85*]. Contemporary average-practice or the worstpractice firm performance can be used in conjunction with best practice performance to provide an economic measure of these kinds of technology gaps.

Kmenta has made attempts to develop lagged models for studying the technological gap. Changes in lags have been found to influence the size of the technological gaps and the relative technological positions of various countries. At present these models represent simple relationships, but their development and the development of other kinds of models promise interesting analytical insights. Efforts to close the technological gap are assumed to be manifested in the acquisition and use of capital equipment [7; 74]. Patterns of gross investment by national and regional firms and industries are thus important indicators of technical change. Studies which view the diffusion of technical change through capital accumulation tend to assume that technical progress occurs at the time the capital equipment is installed because of the technological superiority of the new equipment. This superiority is demonstrated by the subsequent reduction in the average cost of production.

Why then is technologically superior capital equipment not adopted immediately by all similar firms? Profitability is assumed to be a major determinant of adoption in most cases. However, the profitability of firms is not entirely determined by the technological rank or obsolescence of its capital equipment. Quality of management and organizational structure, scale economies, favorability of location, relative factor prices, control over prices, and management attitudes are examples of other factors which also influence the profitability of firms.

To date there are very few empirical studies on the rates of diffusion of innovations in the manufacturing sector [39; 54; 69]. The few extant studies primarily consider the intraindustry diffusion of a few innovations of the embodied kind in a small number of industries. They are, therefore, not representative of the different kinds of manufacturing industries or of different kinds of innovations. No wonder Mansfield remarked recently that there was an urgent need "for much more work of a theoretical and econometric sort" on the rate of diffusion of innovations [54, p. 484].

THE DIFFUSION OF INNOVATIONS

"Continuous disturbance and slow adjustment are essential features of technical change" [74, p. 5]. The manufacturing sector as a whole during the last century has been the recipient of a steady stream of innovations. Evidence suggests that innovations spread relatively slowly through manufacturing industries, thus, one may conclude that adjustment to technical change is slow.

A joint study of the intraindustry diffusion of new technology in the United Kingdom, West Germany, Italy, France, Sweden, and Austria has recently been undertaken by a number of economic research institutes in western Europe [69]. An attempt was made to find out which of the six countries attained the widest diffusion and leadership ranking in terms of the ten techniques examined and when measured by the average speed of introduction of all techniques and the percentage of total output in the respective industries associated with the techniques during various time periods. Analysis of five processes—basic oxygen, continuous casting, tunnel kilns, automatic transfer lines, and shuttleless looms—suggested that countries which are pioneers tend to have *slower* speeds of diffusion. Such results seem to support the generally accepted view that pioneers suffer from the teething problems associated with the new technique; however, caution is suggested, for in two of the techniques studied the pioneer's diffusion speed was the fastest. Special circumstances affected both cases, and may exist frequently enough at various geographical scales, and industry and firm levels to make generalizations with present knowledge hazardous.

A line of inquiry not pursued in the study was the intraregional and interregional distribution of the innovation diffusion. Any explicit consideration of the spatial dimensions of innovation would, however, have required spatial analytic frameworks. Unfortunately, no suitable framework exists for this type of analysis of innovation in the manufacturing sector. Available frameworks devised for other purposes consider technological change within a broad social context [*10*; *38*]. Interpersonal relationships are regarded as playing a crucial role in this setting. Stress is then placed on the spatial dimension of interpersonal relationships, and the friction of distance is generally invoked as a dominant explanatory variable in accounting for the spatial patterns of innovation diffusion. Of course, many factors may distort the nature of the relationship between distance and the sequence of innovation adoption. This is especially the case in manufacturing, where many industries are composed of relatively small numbers of enterprises that are not evenly distributed over any country or region. These factors, combined with the other modifying influences described in earlier sections, encourage a more process-oriented approach to the analysis of the spatial manifestations of innovation decisions.

THE RATE OF INNOVATION DIFFUSION IN INDUSTRIES AND FIRMS

Data from the west European study provide no definitive evidence that large firms are always the leading innovators and the fastest adopters [*69*, p. 83]. Conventional wisdom, however, suggests that, in general, large firms play the lead role because of their greater emphasis on R and D investments, more sophisticated managerial systems, and easier access to capital [*29*; *33*; *59*].

Studies of interfirm rates of diffusion seem to be most conspicuous by their absence in the manufacturing sector. However, Mansfield in a study of diffusion of diesel locomotives found that "there are great differences among firms in the rate at which they substitute an innovation for an older method." In this case,

> a substantial part of this variation can be explained by interfirm differences in the profitability of investing in diesel locomotives, interfirm differences in size and liquidity, and interfirm differences in the date the process of dieselization began. Increases in each of these factors other than firm size result in increases in the intrafirm rate of diffusion [*53*, p. 205].

These may well prove to be important economic factors associated with the intrafirm rate of diffusion within manufacturing industries. Furthermore, what is the explanatory power of the "attitude of management" in considering intrafirm and interfirm rates of diffusion?

Another characteristic of the rate of diffusion within industries is the "bandwagon" or "contagion" effect. Some researchers have found that "as the number of firms in an industry using an innovation increases, the probability of its adoption by nonusers increases" [*53*, p. 204]. Increased interfirm competition and changes in risk or reductions in uncertainties which accompany the availability of more information about the innovation are given as explanations for the bandwagon effect.

Causal Factors. Despite the paucity of empirical studies, there is a consensus that the most significant and general influences on the diffusion of innovations are the advantage of the new technique (or product) in terms of its overall profitability, the attitude of the management to the adoption of new technique, and the firm's access to capital [*69*, p. 83]. The firm's size has also been mentioned as an important factor in influencing the speed with which it begins to use a new technique, especially when it is considered in relation to the profitability impact of the technique [*51*]. However, a firm's financial health does not seem to be closely related to the length of time it waits before adopting a new technique. It also appears that firms, which are in one instance the first to innovate or adopt, have a good chance of not being the next innovators or the fast adopters of the next innovation. Technological leadership can be transitory for the firm, but this does not necessarily mean that its economic or financial leadership is in immediate jeopardy.

The above factors are complemented by a variety of less well-defined influences that constrain or modify the diffusion process in specific industries. For example, existing laws and regulations affected the adoption of Gibberellic acid in west European countries. It is also commonly accepted that patents have an inhibitive effect [*21*; *75*]. Moreover, Ray's study showed that

> numerical control of metalworking machine tools was probably most affected by the nature of the work to be performed—hence the rapid adoption in the aerospace industry; the high servicing requirements—e.g., programming, etc.—might have acted as a deterrent [in the metalworking industry] [*69*, p. 83].

A greater understanding of the process of diffusion will result from studies which probe the nature of the relationship between the rate of diffusion of innovations or imitation and factors such as profitability. For illustrative purposes, let us examine some aspects of this particular relationship.

While it is convenient to assume that a firm views the adoption of new capital equipment from a purely economic viewpoint, it is more probable that management also takes into account, either consciously or unconsciously, many non-economic factors. Within an economic framework, a firm will tend to adopt quickly the new capital equipment if it is superior to the capital equipment currently in use. This will also tend to be the case if its present equipment is worn out. The old equipment is replaced if the reduction in production cost due to the introduction of new equipment is sufficiently large to pay for capital cost (plus a normal return) associated with replacement. Thus, amortized old equipment may, because of profitability, be used in the short run despite the availability of technologically superior replacements. Eventually, rising maintenance costs and technical inferiority will take their toll, and changing profit forecasts will facilitate the adoption of the new machines. The timing of the changeover will also be conditioned by prevailing interest rates and the price of the new capital equipment. If the relative price of capital is higher than that for labor, it will tend to slow down the adoption process. When the scrap value and resale prices for old machines are high and intraindustry competition is intense, adoption will tend to be faster as these factors bear directly on the profit outlook of the firm [*74*].

Of special interest to geographers is the fact that in the studies examined, the "neighborhood effect" has not been mentioned as a factor influencing the diffusion of innovations in the manufacturing sector. Does it mean that in this milieu the "friction of distance" has no important influence on the rate of diffusion, the geographical distributions of innovations, and the spread of innovations over geographic space? It may well be so in the studies examined. Some may wonder, however, if any attempt was made in the studies to identify and evaluate the significance of a "spatial variable." It would be interesting to ascertain if there is a neighborhood effect associated with the bandwagon effect described earlier. This may not hold for all innovations in all industries, but may characterize the diffusion of innovations in spatially agglomerated industrial complexes and urban areas [*67*].

Organization and Management. During the last decade a number of additional perspectives has been suggested with reference to the study of the process of diffusion or transfer of technology. There is a growing belief among students of technological change that management plays a critical role in the adoption or imitation process, as it does in actual innovation [*61*; *62*].

The attitude of management towards innovation and adoption is very important. This is recognized in several classification schemes of firm innovative behavior. For example, firms have been divided into *active* firms where management is "deliberately searching for new markets and new techniques" (an offensive strategy), and *passive* firms where management just responds "to direct market pressures such as excess demand or increasing competition or falling profit markets" (an absorptive or defensive strategy) [*15*; *48*; *63*]. Active firms display a much greater propensity to innovate than passive firms. However, management may be aggressive in one time period and passive or defensive in another. Large corporations at a point in time can be aggressive and innovative with respect to some product lines but very slow in other product lines. Various combinations of seemingly contradictory attitudes toward technological change may be present at the same time in firms. This is to be expected, as many people with different talents, levels of competence, goals, and attitudes contribute to firm decision making, and different mixes of these people may be involved in decisions which bear on different product lines.

Information Transfer. Another important function of management is to generate and facilitate the right kinds of information flows within the firm and between the firm and its environment [*91*; *92*]. Studies on technological changes stressing the information perspective show that major information inputs for innovation and adoption are derived from within the firm, primarily (75 percent) in the form of personal experience and personal contacts of members of the firm [*44*; *61*, pp. 61-2]. External sources of information tend to be more important in the case of adoptions, and vendors frequently play a significant role [*30*].

Technology is embodied in both artifacts and in people [*35*]. Hitherto, greater attention has been given to the diffusion or transfer of technology embodied in artifacts. More recently, interest has grown in identifying the nature and significance of technology embodied in people. Firms have long been aware of the advantages which frequently accrue from hiring key people associated with competitive firms. There is a widespread belief that interfirm mobility of scientific, technical, and certain management personnel is high, and much technological change is associated with the movement of these people [*70*; *72*].

In a carefully documented study, Hall and Johnson examined another interesting aspect of information flow [*39*]. Their findings provide insights into the major role national governments may and do play in diffusing technology nationally and internationally. The authors use the "learning curve" concept as a framework for the empirical analysis in their study of costs connected with the construction of the F104 by Lockheed and Mitsubishi. Interfirm transfer of acquired technology enabled Mitsubishi to produce their first ten F104 planes with fewer man-hours than did Lockheed. Moreover, it was shown that some kinds of technological knowledge are less easy to transfer than others, which, of course, has an adverse impact on the economic cost of transfer. In the case of the F104, 60 percent of the technology was easily transferred, 20 percent was more difficult to transfer, and the remaining 20 percent was not transferred at all.

Hall and Johnson developed a useful classification of technical information for describing and analyzing the diffusion of technology:

> General technology refers to information common to an industry, profession or trade. . . . Systems-specific technology refers to the information possessed by a firm or individuals within a firm that differentiates each firm from its rivals, and gives a firm its competitive edge. . . . Firm-specific knowledge differs from system-specific knowledge in that it cannot be attributed to any specific item the firm produces. Firm-specific knowledge results from the firm's overall activities [39, p. 309].

One can imagine how firms attempt to profit from protecting their economic control over firm-specific and system-specific technology. In particular:

> The decision to sell technology or utilize it within the firm depends primarily on the intellectual property system and the perfection of markets for ideas, factors, and products [39, p. 310].

Further investigations should be made of the *process* of technology transfer, and should be as detailed and as thorough as the one by Hall and Johnson [57]. These studies should focus on various kinds of products and processes, as well as on organization and management systems, for:

> Transfer entails not only a movement of ideas in the form of blue-prints, drawings, and other data, but a movement of material and men. Put differently, a transfer of manufacturing technology for a sophisticated product usually involves a transfer of rights and data, a technical assistance program, and material support. The success and costs of a transfer are importantly influenced by the amount of each class of support [39, p. 355].

The relationship between management and information flows is a topic worthy of further study. The greater importance and use at the firm level of interpersonal channels of communication as compared to mass media channels invite the application of diffusion models of the kind already developed by geographers. It may be useful, though, to focus on resistances in communication channels rather than physical or terrestrial barriers such as intervening distance. In some respects, the firm may be thought of as a social subsystem and undoubtedly generates resistances as well as facilitates channel communication [56]. Work should initially consider the organizational structures of firms and an investigation be made of the connections between organizational structure, firm management, and information channels and flows. Sources and receivers of information should be identified and their decision-making roles in the firm and in the process of innovation and adoption evaluated.

This avenue of investigation would include not only the nature of the relationship between information flows and organization within a firm but also how information is obtained and utilized by other firms in the same industry. An additional issue is whether or not some information flows are confined to firm actors (channels) who have community without propinquity, for example, professional specialists. If these channels are critical to the innovation and diffusion process, then any spatial impact would emanate from the use made of the information rather than from the respective spatial locations of the sources and receivers.

Geographers in particular are interested in the spatial dimensions of the transfer of information within and between firms, and whether or not the intervening distance between sources and receivers influences the rate of diffusion of an innovation and the spatial pattern of subsequent adoptions. Preliminary investigations of connections between organizational structures of firms and the locational patterns of their plants suggest that findings relating to this topic might be integrated with results from the study of the role of information flows in innovation diffusion and adoption [88].

The Nature of Innovations and Adoptions. Various kinds of innovations generate different kinds of changes and impacts within the firm and its environment. Some innovations such as portable television and new cake mix flour are pedestrian in character and require little if any costly change in existing production equipment, marketing, or corporate organization. However, the technical and production complexities and uncertainty connected with the act of innovation increase as one considers such innovations as continuous casting, transistors, numerical controls, and computers [*78*]. The more radical the innovation the greater the number, cost, and significance of the changes brought about in the environments of the innovator and adopting firms. Adoption usually requires adaptation and even further innovation. Some innovations also require considerable investment in infrastructure by the public sector, and often they bring about changes in technologically linked firms in the private sector. These induced changes in turn frequently generate further innovations [*61*, pp. 19–29]. However, there are spectacular exceptions to the generalities described above. For example, a technologically insignificant innovation such as individually packaged food products required major changes in marketing practice. Nylon, a major product innovation, required very little change in the textile machinery used for weaving.

Other Considerations. In this paper it has not been possible to discuss all dimensions of the process of diffusion of technology in the manufacturing sector. Among very important topics which have received only passing reference are the human costs and benefits perceived in innovation and adoption by the blue-collar workers, and an examination of how this group inhibits and facilitates technical change. The various roles of national governments have been alluded to, but this is a complex topic necessitating inquiry about the roles of many levels of government. Another aspect is the nature of relationships between manufacturing industries and firms and their respective noneconomic environments. Little is known about how and why these relationships may affect and be affected adversely or favorably by the technological changes embraced by the acts of innovation and adoption. Finally, there is urgent need to study technological change and the process of diffusion in manufacturing industries and firms located in specific countries, regions, and cities. Such studies carried out in specific geographical contexts will provide valuable insights into the processes which lead to the growth and decline of firms and industries in areas of various scales, economic function, and political organization.

CONCLUDING STATEMENT

The inadequacy of the static neoclassic framework for understanding the nature and process of innovation as well as its diffusion in various forms of adoption has been voiced by Arrow and others. Solo, however, has described the kind of framework we need as one

> that can contain the generation, recapitulation, dissemination of information, the determinants of creativity, the process of learning by individuals and groups, the disintegration and re-creation of ideology and values, the receptivity or resistance to novelty, and the scope of the power and the nature of opportunity and the motivation to transform technology [*81*, p. 863].

In this paper we focused on those elements and relationships which are essential components of such an explanatory framework. Technological change in the manufacturing sector was examined from a number of perspectives. This included an outline of the nature and significance of the relationships between research and development, various structural elements in manufacturing industries, and successful innovation. Various behavioral relationships between the firm, product cycles, and market expansion and technological change were identified and their significances explored.

Technological change was also viewed from the perspective of the firm as an organizational entity. The quest for better management has evoked the development of various organizational structures. Some preliminary thoughts were expressed regarding the relationships between different organizational structures of the firm and the ability and efficiency of such firms to innovate and adopt innovations.

In addition, an attempt was made to demonstrate the need to view the diffusion of technology as a dynamic process. Its complexity as a phenomenon decrees that the process is influenced by many factors which change in nature and impact over time and geographic space. Factors discussed as they related to the process of the diffusion of technological change included, for example, organization and management information flows and the nature of various kinds of innovations and adoptions. While it is tautological that technological change takes place in a spatial as well as in sectoral and temporal contexts, past research has emphasized the sectoral and temporal dimensions of technological change. This paper indicates the nature of the need for and the contextual setting of more information and insights regarding the spatial dimensions. Several lines of future research were also outlined. Finally, we sought to indicate how information and insights on technological change and diffusion in the manufacturing sector might be integrated and incorporated into a variety of conceptual frameworks.

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