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Innovation in Industry and the Diffusion of Technology

James M. Utterback

The impact of technological change on economic growth (*1*), industrial productivity, and international competition and trade has been widely recognized. There is a rapidly developing interest in such issues as the environment for advances in science (*2*) and technology (*3*) and the contribution and relationship of basic science to technology (*4*). Recent debate has focused on the questions of whether and how to provide incentives to firms to innovate and to spend greater amounts on research and development, and whether and how to reduce the barriers to innovation faced by firms (*5*). A wealth of hypotheses and case studies of the process through which technology is created, developed, and used by firms is available and should provide a useful perspective in dealing with these questions. The sources of more than 2000 case studies, the industries or innovations studied, and the sizes of the samples are summarized in Table 1. A simple concept of the factors that limit and determine a firm's effectiveness in innovation and of the phases and relationships in the innovative process is presented below; this concept allows one to compare the findings from these diverse sources.

In this article, I present what we know—or think we know—about the process of innovation by firms. How do characteristics of the environment affect firms' innovation? What factors and information affect the creation and acceptance of ideas for new products? What factors are related to effective development efforts? What do we know about the acceptance of innovations in the market and about the creation of new firms based on technology? Finally, past work in this field

The author is associate professor, Graduate School of Business, Indiana University, Bloomington 47401. This article is adapted from a paper commissioned by the National Science Foundation Task Force on Alternate Federal Policies Affecting the Use of Science and Technology, directed by J. Herbert Hollomon (NSF grant GQ-5), June to December 1971.

appears to have been of a distinctly descriptive and noncumulative nature. What are the crucial issues for research and how might these be approached to yield more scientific, rigorous, and cumulative results?

Any firm's potential for technical innovation can be considered as a function of its environment—including economic, social, and political factors, the state of development of technology, and information about technology. Barriers to flows of people and information between the firm and its environment will limit its knowledge of social and market needs, new and existing technology, and government programs, incentives, and regulations, thus limiting the potential for innovation as seen by the firm. Characteristics of the firm itself, including its resources, personnel, and patterns of communication and decision-making, will determine the degree to which it meets its perceived potential for innovation (*6*).

Innovation, as distinct from an invention or technical prototype, refers to technology actually being used or applied for the first time. The process of innovation is viewed, for simplicity in making comparisons, as occurring in three phases: generation of an idea, problem-solving or development, and implementation and diffusion. Generation of an idea involves synthesis of diverse (usually existing, as opposed to original) information, including information about a market or other need and possible technology to meet the need. Problem-solving includes setting specific technical goals and designing alternative solutions to meet them. Implementation consists of the manufacturing-engineering, tooling, and plant and market start-up required to bring an original solution or invention to its first use or market introduction. Diffusion takes place in the environment and begins after the innovation is introduced (*7–9*).

Environmental Factors

Market factors appear to be the primary influence on innovation. From 60 to 80 percent of important innovations in a large number of fields have been in response to market demands and needs. The remainder have originated in response to new scientific or technological advances and opportunities. These data are shown in Table 2. There is a striking similarity between the findings of studies conducted in the United States and those conducted in the United Kingdom (*10–12*).

Innovation also appears to be stimulated by expanding markets and by rising costs of inputs, with innovations aimed at reducing the use of more expensive inputs (*13, 14*). Firms tend to innovate primarily in areas where there is a fairly clear, short-term potential for profit (*15*). Many innovations of great commercial significance are of the relatively low-cost, incremental type, the result largely of continuous development efforts (*7, 16, 17*).

In most industries, no single firm commands a majority of the resources available for research, nor can any one firm respond to more than a portion of the needs or problems requiring original solutions. It is not surprising, therefore, to find that most of the ideas successfully developed and implemented by any firm came from outside that firm. Of the 157 cases studied by Myers and Marquis (*7*) for which these data are available, 98 of the ideas were evoked by information from sources outside the firm. Mueller (*18*) found that 14 of DuPont's 25 major product and process innovations originated wholly outside that company. Of 59 pieces of information incorporated in the ideas for 32 new scientific and measuring instruments, 39 came from outside the firm that developed the idea (*19*). Langrish (*20*) found that 102 of 158 key ideas involved in generating 51 innovations came from outside sources.

If one examines the innovations named by firms as commercially successful, one finds that a significant number (23 to 33 percent) have been wholly adopted from other firms. These are more often process innovations than product innovations, and tend to be modifications rather than completely new items. Interestingly, the cost of the adopted innovations was about the same as that of the original innovations studied (*7*). This similarity in cost is probably due to the fact that the cost of originating and developing a successful innovation is a minor part (probably 15 to 30 percent) of the total cost of bringing it into use (*21*).

Table 1. Some retrospective studies of technological innovation.

Author	Industries studied	Sample size
Arthur D. Little, Inc. (*27*)	Textiles	12
	Machine tools	6
	Construction	8
	Semiconductors	12
Carter and Williams (*11*)	116 British firms	204
Enos (*14*)	Petroleum refining (processes only)	11
	Other industries	35
Goldhar (*37*)	Winners of Industrial Research Award	108
Hamberg (*22*)	Major innovations 1946–1955	27
Jewkes *et al.* (*23*)	Major innovations 1900–1945	61
Langrish (*12*)	British innovations given Queen's Award in 1966 and 1967	51
Mansfield (*30*)	Iron and steel	49
	Petroleum refining	66
	Bituminous coal	28
	Railroads	10
Miller (*24*)	Steel products and processes	12
Mueller (*18*)	DuPont's major innovations 1920–1949	25
Myers and Marquis (*7*)	9 railroads	79
	14 railroad equipment suppliers	125
	53 housing suppliers	196
	12 computer manufacturers	90
	23 computer equipment suppliers	77
NSF–IIT (*34*)	Magnetic ferrites Video type recorder Oral contraceptive pill Electron microscope Matrix isolation	5
Peck (*15*)	Aluminum	194
Robertson *et al.* (*10*)	Chemicals	34
	Scientific instruments	24
Sherwin and Isenson (*17*)	Weapons systems	20
Tannenbaum *et al.* (*33*)	Major materials developments	10
Utterback (*31*)	Instruments	32

Larger firms do not seem to develop a greater proportion of innovations, relative to their market share, than smaller firms (*18, 22–24*). No consistent relationship between size of firm and number of innovations appeared in the Myers and Marquis (*7*) study except, perhaps, a stronger market orientation on the part of smaller firms. Mansfield (*25*) suggests that size of firm has little effect on innovation, at least when a firm is above some threshold size. Structural factors affect this relationship from industry to industry. Shimshoni (*26*) notes that those smaller firms which are successful innovators in the instrument industry rely largely on government contracts and orders early in their life cycle, later diversifying into commercial areas. In mature industries, such as textiles, machine tools, and construction, innovation is more likely to come from smaller, new firms than from older, large firms, as well as from firms in other industries (*27*). This generalization also appears to be true of the petroleum refining industry (*28*).

There is a substantial lag, 8 to 15 years, between the time technical information is generated and the time it is used in an innovation. The lag appears to vary with industry, product, market, and resources used. Enos (*14*) concludes that mechanical innovations have the shortest interval, with chemical and pharmaceutical innovation next, and electronic innovations taking the most time. In addition, he states that "the interval appears shorter when the inventor himself attempts to innovate than when he is content merely to reveal a general concept" (*14*, p. 309). The lag appears to be shorter for innovations directed at consumer, as opposed to industrial, markets and for innovations developed by government, as opposed to those from industry (*29*). Because of the small samples studied, the above findings are of questionable validity. Finally, the time required to develop and bring an idea to first use appears to be relatively constant, with the median between 1 and 7 years for various samples (*29–31*).

Basic research does not seem to be significant as a direct source of innovations. It plays a critical role in the production of knowledge and enters the process of innovation indirectly, by means of education. This role is partly responsible for the time lag mentioned above (*32*). Tannenbaum (*33*), Sherwin and Isenson (*17*), and the National Science Foundation (*34*) have undertaken studies of the contributions of basic and applied research to innovation. These studies have used widely differing criteria for selecting the innovations studied, for defining and analyzing time lags, and for choosing the time periods to be included, and are not, therefore, directly comparable. The TRACES study (*34*) suffers from having forced an overly rational pattern on the data obtained —assuming that information which appeared relevant in retrospect was actually a factor in the progress of a given innovation (*35*). Both the TRACES and Hindsight (*17*) analyses note that applied research and development concerns often stimulated further basic study. This point is supported also by data reported in the Materials Advisory Board study (*33*). These data strongly suggest that the crucial role of basic research in industrial innovation lies in continual reinforcement and understanding of the implications of applied work.

Table 2. A comparison of studies of the proportions of innovations stimulated by market needs and technological opportunities.

Author	Proportion from market, mission, or production needs (%)	Proportion from technical opportunities (%)	Sample size
Baker *et al.* (*38*)	77	23	303*
Carter and Williams (*11*)	73	27	137
Goldhar (*37*)	69	31	108
Sherwin and Isenson (*17*)	61	34	710†
Langrish (*20*)	66	34	84
Myers and Marquis (*7*)	78	22	439
Tannenbaum *et al.* (*33*)	90	10	10
Utterback (*31*)	75	25	32

* Ideas for new products and processes. † Research events used in 20 developments.

Where data on the individuals involved in generating successful innovations are reported, the conclusion is that they are a well-educated group; however, all levels of education are represented. The median education of the founders of new firms, Roberts (*36*) reports, is the master's degree. This is also true for the originators of innovations reported by Utterback (*31*) and by Goldhar (*37*). Approximately 40 percent of the respondents in each of these samples hold the Ph.D. degree. Personal contacts, education, and experience constitute by far the largest proportion of information sources used in originating ideas for innovations. The data from these studies suggest that education is the primary avenue through which basic scientific findings are translated into engineering practice.

Sources of Ideas

In most cases, ideas for innovations originate with communication about a need, followed by search for technical possibilities to meet the need (*19, 38*). Informal and oral sources provide the majority of key communications about both needs and technical possibilities (*7, 20, 38*). Communication about a need seems often to be initiated by someone other than the person who generated the idea for an innovation, while communication about a technical means is initiated most often by the innovator himself (*19*).

Consultants, consulting activity, and information resulting from diversity in work assignments appear to play major roles in the generation of ideas for successful innovations. For example, outside experts played a crucial part in the generation of ideas for 16 of the 32 new instruments I studied (*9*). Peters (*39*) has explored the relationships among consulting, diversity in work assignments, and generation of ideas in interviews with faculty in four departments at the Massachusetts Institute of Technology (MIT). He found that 96 percent of those reporting ideas engaged in consulting, as opposed to 55 percent of those not reporting ideas. Of those reporting ideas, 70 percent said also that their work was mixed between research and development, as opposed to 28 percent of those not reporting ideas. Gordon and Morse (*40*) also note that consultation outside the work setting tends to enhance generation of ideas. These findings might be explained by the central requirement for synthesis of information in forming ideas. Both consulting and diversity in work assignments would tend to assist in bringing together information about needs and about technical possibilities.

As noted above, in a majority of cases an idea results from recognition of a need, followed by a search for relevant technology. In some cases, however, recognition of a technical opportunity stimulates the search for an application of the new technology or information. Older technical possibilities seldom attract attention spontaneously; in contrast, a new discovery or technical possibility might well attract attention and stimulate a search for applications. Thus, one might expect innovations stimulated by a need to be based on older technology than innovations stimulated by a technical opportunity. This surmise has been supported by several studies (*7, 19, 37, 41*). How can the latest technical information be used in meeting needs? Periodic retraining of technical personnel and concentration on informal communication, personal mobility, and diversity in work and consulting opportunities could serve to reduce the discrepancy between available technology and technology in use.

The above findings may well explain the fact that government-held patents and technical reports are seldom used in a commercially or socially important application other than the specific one from which the patent or information arose. Since application of technology is usually stimulated by a need or market, one would not expect the availability, per se, of patents or technical information to result in application. The findings above do imply that more commercially oriented patents would find greater application, as would patents or information generated in agencies or firms with diverse missions or markets and thus with a greater chance to couple the new technology with needs. Recent data support these expectations (*42*).

Sources of Solutions to Problems

Communications that aid in generating ideas are often initiated by someone other than the person who has the idea. In contrast, information that is important in developing ideas usually comes from communications initiated by the person involved in solving development problems related to the idea. I have found (*19*) that roughly half of all information that stimulated innovations came from communication initiated by someone other than the innovator himself. However, during problem-solving, fully 86 percent of the important information used was the result of communication initiated by the innovator. Myers and Marquis (*7*) note that 17 percent of all information that evoked the basic ideas for the innovations they studied was obtained at the initiative of others. This finding was true for only 3 percent of the cases in which the information was used in problem-solving. In contrast, 12 percent of the information that evoked ideas was the result of search by the innovators, as opposed to 25 percent during problem-solving. (The magnitudes of these differences are not comparable because of the different categories used in the two studies.) I have found (*19*) that oral sources were important both during idea-generation (45 percent of all information) and during problem-solving (32 percent of all information). While informal sources still played a major role during problem-solving, the proportion of inputs from primary sources (analysis and experiment) was found to double from 22 percent during idea-generation to 52 percent during problem-solving. These data all point to a more active and structured search for information during problem-solving (*32*).

Most of the information used in problem-solving comes from within the firm (*7, 19*). However, this information is usually brought into the firm by a few individuals, termed "technical gatekeepers" (*43*), who have more extensive contact than the others do with colleagues outside the firm or with technical literature, or both. These persons are frequently chosen as internal consultants or technical information sources by others within the firm. The findings suggest that, while highly developed, internal technical resources and communication channels are vital to success in problem-solving, information flow from the environment is also critical to effective technical solutions. This appears to be more the case for rapidly changing technologies than for stable fields. Allen (*44*) has shown not only that technical gatekeepers have much greater contact than others with professional literature and oral sources of information outside the firm, but also that they are typically in close communication with others in the organization who share these characteristics. Information tends to be communicated quickly within the gatekeeper network and from the gatekeepers to others in the firm. It is not surprising that the technical gatekeepers account for a majority of the ideas for solutions noted as outstanding by Allen's respondents. It would be difficult to design a more effective system of information dissemination than the one he describes.

Allen (*45*) contends that the complex nature of technical information and of individual user needs provides a strong incentive for the development of such a mediating activity in the flow of technical communication. The lack of success in attempts to design computer-based systems for retrieval of technical information (*46*) is not difficult to understand in light of these findings. In general, one can conclude that increased communication outside of the immediate work group and organization will, other factors being equal, be related to better performance in problem-solving and that increased communication could be achieved more effectively with policies designed to encourage the development of informal channels of communication (*4*) or, at least, designed not to impede this process.

Internal Characteristics of the Firm

Barriers to communication and action within the firm and its resources, organization, and other internal characteristics were noted as limiting the firm's ability to originate, develop, and implement innovations in response to communication with its environment. In general, firms face not one strategy but a rich variety of possible strategies for dealing with a given set of opportunities and problems. Each possible strategy is associated with a cost, and each is more or less appropriate in different environments.

As the uncertainty faced by the firm increases, its need for specialization to deal with varying facets of its environment—such as market, production, and technological factors—also increases. Uncertainty may arise from a number of sources, such as the clarity of information available, the extent of knowledge about causal relationships among environmental factors, and the length of time required to judge the impact of any environmental change or management action. Regardless of the levels of specialization, the need for integration among functions appears to remain relatively constant; however, the difficulty and cost of achieving integration among functions will increase as specialization increases (*47*). This increase is even more pronounced when a firm faces rapid, short-term fluctuations in its environment, perhaps as a result of government actions, and must resort to temporary expedients to achieve needed integration (*48*). Inappropriate managerial responses, such as demand for a highly structured organization in a rapidly changing environment, or use of too few, poorly placed, excessively costly or excessively permanent integrating devices, will usually be associated with poor performance by the firm (*47, 49*).

Organizational and spatial bonds might be expected to affect communication and integration among functions and between phases in the innovation process (*50*). For example, transfers of technical personnel among divisions, other factors being equal, would be expected to result in a temporary increase in communication between the divisions. This increase would be particularly likely if the person transferred was a part of, or was linked to, the gatekeeper network in one or both organizations (*51*). Retention of a liaison person or group as a project moves from idea-generation through problem-solving to implementation has been suggested as an effective strategy for integration (*52*). Architecture exerts a significant impact on communication, with frequency of communication falling off very rapidly with increasing physical barriers and distance among people (*44*).

These factors have been examined by Marquis (*53*) in an extensive study of the relationship between organizational structure and project success. Organization of technical personnel by function was found to be related to more effective technical performance, while organization of administrative personnel by project was related to more effective cost and schedule performance. Marquis concludes that a hybrid, or matrix, organization, in which there is a small project team but where more than half of the technical personnel remain in their functional departments, is the best option. This type of organization is more likely to meet needs for both specialization and integration in an uncertain environment than either a total project or a total functional organization; thus, this type of organization is more likely to achieve technical excellence and, at the same time, to meet cost and schedule constraints. In more stable technical fields, the need for specialization would be less, and therefore the disadvantage in terms of impairment of technical performance of a total project organization would be reduced (*45*).

Marquis (*53*) found that projects having some slack resources not only achieved better cost and schedule performance, virtually by definition, but also tended to have better technical outcomes than those without slack. This finding underscores the generally adverse relationship between time and cost, on the one hand, and technical quality, on the other. Achieving a given technical advance in a reduced period of time generally results in much higher costs. Some devices, such as PERT (Program Evaluation and Review Technique), designed to alleviate this problem have aided in improving communication among superiors and subordinates, but they have not necessarily resulted in fewer cost overruns or fewer delays. The cost of innovation will clearly be lower, and the chance of effective technical performance greater, if needless environmental uncertainties can be avoided or reduced, because the resources required for integration will be correspondingly less.

Diffusion of Innovations

Diffusion of innovations in the market is considered to be a two-step or multistep flow similar to the gatekeeper phenomenon described above (*54*). In consumer markets, diffusion begins slowly, with a few influential individuals' use of the new product or process; their experiments initiate wider communication and use of the innovation (*55*). These propositions have been explored fully in cases where individuals or families are the purchasers; there is a much smaller body of research on adoption decisions by firms.

The probability that a given firm will adopt a product or process is thought to be an increasing function of the proportion of firms in the industry already using it and of the profitability of doing so, but a decreasing function of the size of the investment required (*25*). The relative advantage afforded by an innovation seems to be the primary determinant of whether or not it is adopted in an industrial market. Relative advantage may be the result of a change in either a product or a process leading to a reduction in the average total cost of production per unit. Relative advantage may also be the result of increased demand for the finished product because of improved product quality or variety, which leads to increased total revenue. Finally, relative advantage may result when an innovation allows an increase in price and thus a higher average revenue per unit.

Another factor involved in the adoption decision is the degree of associated risk because of the absolute cost of an innovation, its cost relative to the firm's resources, and the ability and willingness of the firm to absorb the costs of a wrong decision (*56*). Rising aspirations, based on increased sales, profitability, and market share, as well as expanding markets, may also encourage adoption. However, Gold's analysis (*57*) of the diffusion of 14 major innovations in the steel industry fails to support this proposition. Although he found no cases of rapid diffusion without rapid growth in output, both medium and slow adoption rates were associated with all categories of growth rates, including zero and negative rates. Neither does relative advantage offer an explanation of why and under what conditions firms will seek higher profits by adopting innovations rather than by choosing other alternatives.

The rate of diffusion of an innovation can be measured with respect to the percentage of firms that have adopted the innovation, or with respect to the percentage of total output accounted for by the innovation. Diffusion rates appear to depend on informal and personal communication for much the same reasons that communication about technology during problem-solving does. The information involved is complex, buyers have varying needs, and information and needs tend to change continually, requiring a flexible communication linkage.

Early awareness of an innovation appears to depend on external sources, such as advertising and vendors (*58*). Evaluation and adoption, however, seem to depend to a greater extent on communication with technical personnel inside the adopting firm. At each stage in the adoption process, the amount, quality, and value of information available appear to have an impact (*59*). Factors that may tend to retard diffusion include the degree to which an innovation is incompatible with existing processes and requires major process changes, the degree to which increased technical skills are required to use the innovation, and the probability that major improvements will rapidly alter the innovation, making delay in adoption advantageous (*56, 57*).

No relationship was found between the size of a firm and its relative ability to innovate. Similarly, there is no evident relationship between firm size and speed of adoption of innovations. Larger firms appear to lead in some industries, while smaller and medium-sized firms lead in others. Nor does leadership in adoption appear to be concentrated in particular firms in the few industries for which data are available. Webster (*56*) contends that larger firms, more able to afford the new investment required for adoption and more able to tolerate the risk of adoption, will adopt innovations earlier. However, smaller firms are more likely to value the technology involved in adoption and to have less complex decision-making processes, which may lead to earlier adoption.

One clear implication of the above findings is that there is a significant time lag between the appearance of a new technology and any wide economic and social impact of its use. While firms may adopt technology for their own short-term advantage, monitoring the initial outcome of such adoptions should provide a means for determining long-run social and economic consequences. Where adoption of an innovation is judged desirable, this adoption may be encouraged by incentives designed to increase the relative advantage to be gained from adoption or to reduce the risks associated with adoption.

New Firms Based on Technology

In addition to output, skilled persons and technical information flow from a firm and become involved in the creation of additional innovations. This type of flow from technically based firms may have a greater effect on employment and the economy than the activities of the parent firm itself. The spin-off ventures formed are characterized by high growth and survival rates and by a high degree of technology transfer into new markets. Roberts (*60*) and Cooper (*61*) have studied such transfers and spin-offs in the Boston and Palo Alto areas, respectively. The economic and social impact of new ventures formed by technical entrepreneurs leaving established firms can be seen from data gathered on spin-offs from the MIT Lincoln Laboratory. The 50 new ventures formed prior to the study had resulted in a total employment greater than that of the Lincoln Laboratory itself, a constant 1800 people. Similarly, 36 ventures that were spin-offs from a large Boston electronics firm over a 5-year period had total sales exceeding those of the parent firm at the end of the period. The better-performing half of 84 firms studied by Roberts (*36*) exhibited a high degree of technology transfer from the parent organization.

There is some evidence that spin-offs are a function of the environment both inside the firm itself and in its geographic area. For example, spin-offs tend to occur in areas of application that have large number of potential parent firms and organizations, as opposed to attractive new areas. The majority of entrepreneurs tend to have a development orientation rather than a research orientation and generally tended to be frustrated by constraints or other factors in their previous jobs (*62*). Some evidence indicates that the recent flux in scientific and technical employment has resulted in a relatively greater formation of new enterprises. This finding may be tempered by a higher failure rate for these firms.

Many of the spin-off companies studied began as government contractors or as sellers of products for defense and space purposes. In time, these companies usually increase their sales to commercial markets (*36*). This mode of entry is clearly dominant for new firms in the scientific instrument industry (*26, 31*). These new firms also typically involve a high degree of advanced technology and technology that was transferred from other organizations and developed to penetrate new markets and areas of application.

Conclusions

The varied definitions used in the sources that have been discussed make any aggregate analysis difficult. A simple three-stage analysis of flows to, from, and within the firm was used to facilitate comparisons. Even so, each of the generalizations is drawn from relatively small and unrepresentative samples. Case studies may continue to be a source of ideas and hypotheses for further research, but do not appear to offer a means for deeper understanding of the innovation process. The retrospective nature of nearly all of the sources discussed probably means that the process has been viewed as much more rational and well-ordered than it is in fact. This failing is partially overcome in firsthand accounts such as those of Suites and Bueche (*63*) and Frey and Goldman (*64*). Each of these accounts involves a successful innovation according to technical or commercial criteria, or both. However, many of the characteristics of innovations that have failed commercially (*10*) appear to be similar to those of successful cases. The few longitudinal studies, and studies comparing more and less successful cases, do support the main conclusions drawn above (*10, 32, 38*).

More serious problems are raised by the distinctly nonrepresentative nature of the samples used. There are few cases (*17, 33, 65*) in which the contributions of more than one organization, or details of interactions over a significant period of time, are discussed. There is a wide variation in the importance of the innovations included, ranging from those affecting the economy as a whole to cases involving production in a single firm, albeit with significant commercial results (*66*).

In addition to questions of comparability and sampling, a central problem for further research on innovation will be to devise an operational model to account for interfirm and interindustry differences. Polar definitions used in past studies, "high technology" and "mature industry," for example, are insufficient.

One possibility is to use the strategy for growth or competition evident in a firm or an industry, such as sales maximization (automotive), cost minimization (transportation, communications), performance maximization (aircraft, chemicals), or control of materials resources (mining, petroleum), as a basis for drawing distinctions (*67*). For example, in an industry that seeks to maximize sales, one would expect innovations that would be highly visible to consumers to be developed rapidly (*68*). In a cost-minimizing situation, production, as opposed to product technology, would be a major source of uncertainty, while the reverse might be the case in a performance-maximizing situation. Greater uncertainty arising from technical sources would imply greater sophistication in effective firms' product planning approaches, while a more stable technology would imply greater sophistication in market research and market-oriented strategies for innovation, and so forth. Much more work is needed along these lines if outcomes of interventions in the innovative process are to be predicted with any accuracy.

Some implications for providing incentives and reducing barriers do seem clear from the work to date. Effective directions for federal action lie in strategies such as creating new markets through purchases or procurement policies; aggregating or focusing markets through regulation and other means; providing for market entry by contracts to smaller firms, venture capital, stronger patent protection, and so on; and providing for mobility and informal contacts within the technical community. Technology "push" strategies (such as tax incentives) to increase most research spending, prizes for new technology, and documentation and information retrieval systems would probably be less important in stimulating innovation.

Definitive answers will require the most difficult kind of research—experiments in the field. Since the interventions required are difficult and expensive in most cases, they will not be under the researcher's control. Nor will the effect of policy changes be visible over a short period. Thus it seems imperative to take advantage of interventions that occur fortuitously to construct "quasi-experiments" (*69*) with as great a degree of control over other factors as possible. For example, have recent changes in policy regarding federally held patents increased the commercial use of these patents? Have changes in the capital gains laws retarded the development and growth of "spin-off" enterprises? Has the identification of technology gaps (*3*) and competitive opportunities stimulated innovation? The effects of such actions on technical innovation could be carefully observed with a modest but sustained research effort, which promises to yield valuable information beyond that available from largely historical sources.

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