SUMMARY

A number of recent empirical studies of technical change at the level of the individual firm have concluded that market demand is the dominant influence upon the innovation process, "calling forth" innovations in market economies. The pace of innovation in the private sector heavily influences the growth of national output and productivity, and these studies and their conclusions have therefore received much attention, having been extensively quoted in discussions of appropriate government policy for the encouragement of innovation. This paper reviews a number of these studies and concludes that their findings, and the interpretations of their findings in the secondary literature, are seriously flawed and, in many cases, invalid. The proposition that market demand governs the innovation process is by no means conclusively demonstrated in these studies, and they are therefore inadequate and inappropriate guides for the formulation of policy.

Most of the studies examined employ a working definition of "demand factors" which is so broad as to embrace a range of possible influences upon innovation which should more properly be classified elsewhere. The concept of demand utilized in these studies bears little resemblance to the more restrictive and precise definition of market demand found in economics. In addition, the phenomena analyzed in these studies are a very heterogeneous lot; the studies do not address identical empirical questions, and their findings are, as a result, neither uniform nor unambiguous.

Both demand and supply side influences are crucial to understanding the innovation process, and it is the exclusive preoccupation with only one set of these forces which is criticized in this paper. Some implications of the criticism for government policy toward innovation are discussed in the conclusion.

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the influence of market demand upon innovation: a critical review of some recent empirical studies

by
David MOWERY and Nathan ROSENBERG
Stanford University, Stanford, CA 94305, USA

INTRODUCTION

Until quite recently, economists devoted little attention to the factors which influence the rate and direction of innovation. Much of the formal economic theory on technical change is really concerned with the description of the consequences of technological innovation at a very high level of aggregation or abstraction. (We have in mind here the works of such economists as Harrod, Hicks and Denison). Little consideration has been paid to the study, at a less aggregated level, of the specific innovative outputs of industries and firms, and the forces explaining differences among industries, firms, and nations.[1] Serious empirical work on biases and inducements in the innovation process, at an industry or firm level of analysis, is even more conspicuously lacking. A recent theoretical literature has been rather inconclusive – with results turning to a distressing degree upon the nature of the assumptions and the particular form of characterization of rational behavior.[2]

An understanding of the innovation process at this level is, however, essential. Obviously, an understanding of the influences which motivate innovation, and channel its direction, is necessary if government intervention is to be successful in increasing the production of useful innovations in specific areas. Awareness of the need for empirical analyses along these lines has been joined to a sense of greater urgency concerning the need

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1 One of the most important recent attempts along these lines was the historical work of Habakkuk [15], which gave rise to an interesting discussion. (See also [7], ch. 1)

2 See [37], [19] and [36] for a sample of this extensive literature.

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for conscious intervention on the part of the government, in view of the growing concern with problems of slower growth in productivity and income, environmental and urban decay, and resource, energy and balance-of-payments constraints which appear to face many countries in the 1970's and beyond.

A number of new empirical studies of innovation have, accordingly, been funded by governmental bodies, while the conclusions of older ones have been exhumed and re-interpreted, in an effort to inform the policy-making process. These studies, and summaries of earlier ones, have led a great many scholars and officials to the conclusion that the governing influence upon the innovation process is that of market demand; innovations are in some sense "called forth" or "triggered" in response to demands for the satisfaction of certain classes of "needs." At the same time, after the buoyant optimism of the early 1960's, disillusionment over the utility of pure research has set in; in America, Federal funding of basic research at continued high levels has been challenged as not contributing to the solution of pressing economic and social problems, and NSF has established its Research Applied To National Needs program. Clearly, these new attitudes reflect more than merely the influence of the empirical studies, but such studies have seemed to provide ample justification for new policies which emphasize the decisive importance of "demand-pull," and at the same time minimize the potential effectiveness of "supply-push" policies.

Yet, whatever the merits of this questioning of the earlier assumptions and goals of science and technology policies, the notion that market demand forces "govern" the innovation process is simply not demonstrated by the empirical analyses which have claimed to support that conclusion. This paper will provide a critical survey of a number of the empirical studies of innovation, in order that their findings and methodologies, as well as their general conclusions, may be evaluated. We will show that the concept of demand utilized in many of these studies is a very vague one, often so broad as to embrace virtually all possible determinants of the innovative process, and therefore to rule out almost all other influences. In addition, as we will see, the studies really do not all examine the same dependent variables, but rather focus upon a number of different aspects of the innovation process in varied environments. This realization has escaped the attention of many writers who have based particular policy recommendations upon the "evidence" of these studies.

Our purpose, obviously, is not to deny that market demand plays an indispensable role in the development of successful innovations. Rather, we contend that the role of demand has been overextended and misrepresented, with serious possible consequences for our understanding of the innovative process and of appropriate government policy alternatives to foster innovation. Both the underlying, evolving knowledge base of science and technology, as well as the structure of market demand, play central roles in innovation in an interactive fashion, and neglect of either is bound to lead to faulty conclusions and policies.

What is needed to sort out the issues and improve the formulation of policy is a stronger predictive theory of innovation, one which goes beyond simply considering the motivations of individual firms to undertake research projects, and which deals instead with the mechanism by which this motivation may be transmuted into an innovative response of a particular sort, one influenced heavily by such factors as the supply of applicable science and technology (factors which also influence the nature of the problems posed for an innovative solution in the first place). Rather than simply referring to "lags" in the process, a useful theory of innovation must try to explain the varied length and distribution of such delays in the response to "needs." What factors serve to focus the problem-solving search upon certain solutions and when do these solutions appear? Such an analytic schema must explicitly consider institutional structures and dynamics, rather than the static analyses to which many theorists are wed, with some precision; the analysis should also be applicable at a fairly high level of aggregation, allowing international, inter-industry, and intersectoral comparisons to be made.

We will first examine the empirical studies, followed by a discussion of how the "findings" of these studies are being interpreted and extended. In the concluding section, we discuss some policy implications of the critique.

Myers and Marquis

One of the most important and frequently-cited of the studies purporting to demonstrate the primacy of demand in the innovative process is that by Myers and Marquis [23]. The aim of their study was "to provide empirical knowledge about the factors which stimulate or advance the application in the civilian economy of scientific and technological findings" ([23], p. iii), focusing particularly upon the development by private firms of design concepts and the character and sources of information used in the subsequent development of innovations. Based upon an examination of some 567 innovations in five different industries, Myers and Marquis conclude that "Recognition of demand is a more frequent factor in innovation than recognition of technical potential" ([23], p. 60). However Myers and Marquis use an extremely loose definition of "market demand" in reaching this conclusion, and their taxonomy of the innovative process does not support such a sweeping statement.

The basic methodology employed in the study was that of interviewing executive and technical personnel in various firms within each of five industries; railroads, railroad-equipment suppliers, housing suppliers (e.g., paint and glass producers), computer manufacturers, and computer suppliers (e.g., peripheral equipment). These industries were chosen "to permit comparison of more technologically sophisticated industries with those which are less technically advanced" ([23], p. 10). However, the basis for classifying firms as members of these industries is nowhere specified, and, with the exception of railroads, none of the industrial categories correspond to those employed in the Census of Manufactures.[3] Rather than dealing with different general classes of innovation in their study, the authors are actually concerned with innovation in the producer-goods industries only, as are most of the other studies examined here. This group of industries may be characterized by a greater degree of "consumer sovereignty" than other industrial sectors, as the qualities demanded in products are communicated more clearly to producers in this sector than is the case for consumer goods industries.[4] It is important to remember throughout this survey that the studies discussed are concerned with a subset of the range of product and process innova-

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[3] Thus, railroads are lumped together with four manufacturing industries. In addition, the composition of the housing, railroad, equipment, and computer suppliers' industries is quite troublesome, since firms in all of these industries are often very diversified. Housing products comprised less than 10% of the output of some firms placed by Myers and Marquis in the housing supplies industry.

[4] In the terminology of the studies by Teubal and the Falk Innovation Project, discussed below, "market determinateness" is quite high in these industries. Pavitt and Walker have pointed out that "... users of innovations in industry and utilities in general know what they want, and whether they are getting it; when they are not, they can say so, which means that innovating firms aspiring to be successful must be sensitive to user needs. However, the same is not necessarily true in consumer markets or in those for public services, which are very far from 'perfect' in the sense described above... the market for public services is often fragmented... neither public services, nor individual consumers, may have the information and technical competence (or the resources to acquire it), necessary for the specification or evaluation of desired innovations" ([28], p. 43).

tions, and "lessons" from producer goods innovations should be applied elsewhere only with considerable care.

The innovations examined by Myers and Marquis were chosen by executives in 121 firms in the five industries in response to a questionnaire asking for the "most important" innovations in the previous five to ten years. The innovations examined are thus all successful, and highly successful ones at that – a selection bias which, it is argued below, the Myers and Marquis study shares with others, and one which influences the conclusions reached in such analyses. The authors also asked the executives to assess the cost of these innovations; but no systematic assessment of the differential importance of individual innovations was undertaken. Such an index, whether defined in terms of increased sales or pecuniary savings, could have been used to weight the various innovations by their importance, a procedure which might have produced rather different results.

In conducting the personal interview with company executives and technical personnel, the authors employed a two-stage taxonomy of the innovation process, consisting of "(1) the idea-formulation stage, in which the recognition of potential demand and of technical feasibility fuse in a design concept, and (2) the problem solving stage leading to a testable item'" ([23], p. 40). Prior to these two phases in the innovation process, according to the authors, is that of "recognition of both technical feasibility and demand" ([23], p. 3). In their schema, "demand" can be either current demand, or potential demand, which largely deprives the concept of market demand of any operational meaning. Potential demands may exist for almost anything under the sun, and the mere fact that an innovation finds a market can scarcely be used as evidence of the undisputed primacy of "potential demand-pull" in explaining innovation. Nowhere do Myers and Marquis deal with the existence and size of any lags between these three phases of recognition, conceptualization, and problem-solving: their framework thus has little predictive power, in that it does not specify any speed of response with which demands "call forth" innovations. Nor, since we are dealing only with a universe of successful innovations, can we examine situations where demand-pull has failed to generate a successful response. All that has really been established is that there was an adequate demand for those innovations which turned out to be successful. We agree, but how would we disagree?

The authors' intent is to focus upon the conditions underlying the production of an innovation, and not at all upon the conditions surrounding its diffusion (commercial adoption). They exclude the phase of "implementation" from consideration, meaning by this term the actual production or use by the innovating firm of the product or process. However, the fact that only highly successful innovations are analyzed implies the existence of an identification problem, as it is difficult in retrospect to separate factors which underlay idea formulation and problem-solving from those influencing diffusion.

The authors conclude from their extensive interviews concerning the stimuli to undertake the research activity leading to a successful innovation that the "... primary factor in only 21 percent of the successful innovations was the recognition of a technical opportunity. Market factors were reported as the primary factor in 45 percent of the innovations and manufacturing factors in 30 percent, indicating that three-fourths of the innovations could be classed as responses to demand recognition" ([23], p. 31). This is a very important finding, which has since been given wide currency in the literature, and its empirical and conceptual underpinnings therefore merit close examination. What are considered to be instances of "technical opportunity"? These are defined as "Cases in which the dominant and immediately motivating factor was the perception of a technical opportunity to create or improve a product or the production process" ([23], p. 79). This is the most restrictive definition of "technology push" possible, one in which a technical breakthrough somehow appears serendipitously, and is applied without any consideration of commercial feasibility. Obviously, *both* commercial and technical feasibility are crucial to successful innovation; the blind application of technical or scientific knowledge implicit in Myers and Marquis' definition of "technological opportunity" is dysfunctional for the capitalist entrepreneur, to say the least.

The conclusions of the study concerning the stimuli for innovation, moreover, are drawn from a heterogeneous set of cases; 23 percent of the 567 innovations examined by the authors in this section of the study are in fact not innovations developed by the firm interviewed, but rather were adopted from some external source. In considering the factors motivating an individual firm to devote resources to research and development, the influence of the underlying scientific and technological knowledge base may be fundamental (we contend that this influence is vastly underestimated in these studies). The decision to adopt an externally developed innovation, however, is not one which is so dependent upon the constellation of technical opportunities which may arise out of the existing stock of scientific and technical knowledge. The innovation, after all, *already exists*. It is therefore inevitable that the inclusion of this substantial subset of firm-level decisions, which involve adoption rather than innovation, will lead to an underestimation of the "push" to innovation afforded by the underlying knowledge base.

The definitions of "market" and "production-related" influences upon the idea generation process, and the lumping together of these two categories under the rubric of market demand in Myers and Marquis, are open to serious question.[5] Of the three categories of influences upon the innovation process, none can be said to be unambiguously "demand-pull" according to any rigorous definition of this concept. Changes in performance or reliability standards are not necessarily identical with a shift in the demand curve. The use of "anticipated potential demand" is very suspect, particularly since it is a concept which really can have meaning only in hindsight, and additionally because of its weakness as a predictive concept; myriads of very deeply-felt needs exist in the world, any one of which constitutes a potential market for some product, yet only a small subset of these potential demands are fulfilled. The recognition of the potential demand may precede the innovation by centuries; does this length of time constitute a mere "lag" in the innovation process?

Data on the length of time required for the metamorphosis of a "design concept" into a successful innovation are nowhere provided by Myers and Marquis; without some such information, no predictive or disprovable theory of innovation can be developed from these findings. The final "market-related" category, "response to competitive product," is basically a defensive response theory of innovation and product differentiation, denoting a rather different theory of innovation from that considered to be "demand-pull." For here, the innovation is "called forth" not by an increase, but rather by a *shrinkage,* in demand for a specific firm's product, due to the actions of a competing firm. This hardly constitutes support of a demand-pull hypothesis – to put it mildly – since the innovation is elicited by an anticipated *reduction* in demand! One might expect this final category of "recognition" to produce the least fundamental or radical innovations;

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5 "Market-related" influences include "changed market requirements" (11.3% of the innovations), defined as "Cases in which the firm encountered a changed market for its product, either one requiring high performance or reliability standards or a change in demand;" "Anticipated demand" (23%), which are "Cases in which firm undertook the innovation because it anticipated an opportunity to market a 'new' product," or more of a modified existing product; and finally, "Response to competitive product," (10.7%). which are "Cases in which a competitor's marketing of a new or changed product induced the firm to reexamine its own product" ([23], pp. 78–79).

in the absence of any data from the authors, we do not know. This defensive-response pattern of innovation, if it exists, also may lead to an over-investment in R & D by individual firms, for each of whom the private return exceeds the social return to innovative activity (see [17]).

The "production-related" categories pose some equally difficult problems of definition; most of them seem to point toward a theory of innovation which emphasizes technical interrelatedness or complementarities far more than market demand as the fundamental influences. These "production" factors include "Change in production process or design which made the innovation or related change necessary" (5.6%); "Change in production process or design which made feasible the innovation or related change" (5.3%); "Quality failure or deterioration (1.1%); "Attention drawn to high cost" (6.2%); "Attention drawn to problem or inefficiency" (10.2%); and "Purchase of new equipment, including replacements of old" (0.5%) ([23], p. 79). All of these factors are doubtless of importance in focusing problem-solving attention and thus influencing the direction of innovation. It is very difficult, however, to see how these factors can be considered as primarily market demand-related, since they do not in any obvious way deal with either actual or anticipated increases in market demand for the products of the firms surveyed. Indeed, the influences classed as "production-related" by Myers and Marquis are not mediated by the market at all, but are internal to the firm.

"Production-related" factors could affect market demand in a very specific set of circumstances. If the market demand curve faced by a firm manufacturing capital goods is shifted by a change in the relative prices of the factors of production used by customer firms, one may posit a connection between the influences which we classify as production-related or supply side ones, and market demand. However, this more complex linkage is not set forth in any of the studies reviewed here. Such a case, in which a shift in relative factor prices alters a firm's choice of technique and thereby influences the direction of technical change, is one which has long been set forth as inducing a factor-saving bias in the direction of technical change. The proposition that changes in the relative prices of factors of production affect the direction of innovation, however, is by no means a proven one; debate over this issue has filled the historical and theoretical literature in economics.[6] Furthermore, while the

[6] Important works in the historical debate include [33], [15] and [42]. Theoretical considerations of the issue are in [16], [9] and [7], ch. 1.

choice of technique employed in production by a firm can change, this may affect only the adoption and diffusion of a particular innovation, not the appearance of a specific type of innovation. To make any predictive statement about the timing and specific character of an innovation, one must know more than the fact that a demand exists for innovation.

Myers and Marquis also collected data concerning the "problem-solving," final design phase of the innovation process. These data primarily dealt with the sources and characteristics of the information which influenced the final, specific character of the new product of process. Again, one is struck by the artificiality of the authors' conceptual approach to innovation. How can the processes, and therefore the influences upon these processes, of "recognition" and "problem-solving," be meaningfully distinguished? Is not the innovation process entirely one of problem-solving, of loosely directed search? The Myers and Marquis vision of a complete "design concept," emerging out of an ill-specified phase of "recognition," seems grossly oversimplified. Adherence to this schema causes the authors to misinterpret their own empirical results, particularly in the analysis of the informational inputs to the problem-solving phase of the innovation process.

The authors categorize the impact of information utilized by the innovating firm either as having "evoked the basic idea," or having "expedited the solution" of the problem.[7] Their findings on the influence of technical or scientific information in the innovation process seem to contradict their previous conclusion that 75 percent of the innovations studied were responses to market demand. For if the timing, specific form and design, indeed function, of an innovation are direct results of the technical or scientific information utilized in its development, how can one also claim market demand as the dominant influence upon the rate and direction of innovation? In the analysis of information inputs to the innovation process, we find that 21 percent of the innovations categorized in the earlier analysis of motivational factors as responses to

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[7] The first category, comprising some 27% of the cases considered, was defined as "cases in which the information provided the basis for the idea (or 'point of departure') for an innovation. The innovation may be viewed as solving a problem which previously had not been conceptualized." Information "expedited the solution" in the other 73% of the innovations considered by Myers and Marquis. In 55.9% of the cases, the expediting information "stimulated the idea or provided the solution of the problem being worked on;" in 9.2% of the innovations, the information simply "expedited the progress of the innovation being worked on;" information "narrowed the area of solution or demonstrated whether or not feasible" in 7.9% of the innovations ([23], pp. 80–81).

demand were classified in this section as innovations in which the problem was not even being worked on, until some technical or scientific informational input provided the basis for an idea. It is very difficult to see any significant difference between this class of innovations and innovations which were motivated by "technical factors."

In their examination of the role of scientific and technical information in innovation, the authors find that the evocation by some informational input of the basic idea for a problem which was not being studied or worked on accounts for 27 percent of the innovations examined in this section of the study. In addition, ideas or solutions for 55.9 percent of the innovations were stimulated by technical and scientific information; i.e., the innovations probably would not have appeared without some informational input. In all, then, some 82.9 percent of the innovations considered by Myers and Marquis were heavily (or totally) dependent upon some technical or scientific information for their appearance ([23], pp. 80–81). Again, if one is to develop a predictive framework to understand innovation, explanation of the form and timing of innovations is rather important. Can one accept the conclusions of the authors about the importance of market demand if in fact some 83 percent of their innovations are so heavily dependent for their emergence upon the stock of technical and scientific knowledge? Clearly, Myers and Marquis have not provided a persuasive empirical case to support their belief in the "primacy" of demand forces in that innovative process.

Langrish et al.

The work by Langrish, Gibbons, Evans and Jevons, *Wealth From Knowledge* [20] is one of the most painstaking of all of these empirical analyses of innovation. This group undertook detailed case studies of some 84 innovations which received the Queen's Award for technological innovation in 1966 and 1967, and all of which were commercially successful. The objectives of the study were

> ... first to provide some rather detailed accounts of what actually happened in recent instances of technological innovation... we aimed in particular to relate the technological to the organizational and other aspects. ([20], pp. 4–5).

The methodology of this study was broadly similar to many of the others reviewed here, although particular care was taken to ensure compatibility among the case studies and to gain a substantial familiarity with the technical and commercial context of each of the 84 innovations, nearly all of which were product innovations of a producer-goods nature. An initial request for general information from one of the innovating firms was followed by an intensive survey of the scientific, technical, commercial and patent literature relevant to the particular innovation. The objectives of this analysis were to gain an appreciation for the environment out of which the innovation arose, and the technical, commercial, and competitive conditions which surrounded the development process. Only after this survey were the technical and managerial personnel in each firm interviewed. The interviews were conducted with an eye to obtaining non-conflicting answers to similar questions from personnel at different positions in the firm; as the authors noted, "questions about the origin of an innovation led to quite different answers and this led to the realization that in many cases, even from the point of view of one firm, innovation is not a simple linear process with a clearly defined starting point" ([20], p. 84).

For 51 of the 84 innovations, the "major technical ideas or concepts" utilized were identified (158 ideas or concepts in all) in an effort to study the sources of, and transmission channels for, knowledge utilized in the innovation process. No attempt was made to categorize the functional or organizational origins of these ideas, however, as was done in the HINDSIGHT and TRACES studies. Although no analyses of the economic impact of the innovations were undertaken, a very important feature of this study is the attempt to classify the innovations by the size of the change in the technology which each represented, defining a particular technology as " a body of knowledge or industrial practice... sufficiently developed to provide a university course at M.Sc. or final-year B.Sc. level" ([20], p. 65). The method by which this change was measured was rather crude, consisting of ranking each innovation on a five-point scale according to the revisions in a standard course textbook necessary to accommodate the innovations.

Although this study's conclusions, as we will see, are frequently cited in support of the primacy of market demand in the innovation process, the actual approach adopted in *Wealth From Knowledge* was one which largely rejected the demand-pull schema in its cruder forms, as the authors concluded that "linear models" of the innovation process were unrealistic, noting that "the sources of innovation are multiple". This rejection of the linear model of innovation derived in part from the conceptualization of scientific and technical research as separate areas of endeavor, with only limited interaction. What little interaction takes place was viewed by the authors as a two-way flow of ideas and resources, rather than a undirectional flow from science to technology. In discussing the importance of "need", which is not well-distinguished from market demand, the authors noted that

> Clear definition of need plus efficient planning fails to account satisfactorily for the majority of innovations. It is not exceptional for the need eventually met to be different from that foreseen and aimed at earlier on. ([20], p. 50).

The authors concluded that "perhaps the highest-level generalization that it is safe to make about technological innovation is that it must involve synthesis of some kind of need with some kind of technical possibility" ([20], p. 57).

A number of statistical analyses of the data for all 84 innovations were carried out by the authors. Of all the innovations examined, only 11 (13.1%) were fairly major changes; the separate analyses of this class reveal some interesting contrasts. Seven factors were identified as playing an important role in all of the innovations. Of these seven factors, "need identification" was found to be important in 16.7 percent of all innovations: "This factor is, of course, present to some extent in most innovations, but in some cases it was possible to demonstrate that the identification of a need was a major reason why the Award-winning firm succeeded in the innovation instead of its competitors" ([20], pp. 67-68). "Need identification" was the second most prevalent factor identified as important in the innovations examined.[8] Here, as in the other studies, the failure to include commercially unsuccessful innovations means that some of these factors must be viewed as aiding in the commercial diffusion and adoption of the innovations, rather than influencing their invention and/or development processes. In addition, some of the factors such as resource availability, or good intra-firm cooperation, surely must have been important in most if not all of the innovations, and perhaps should

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[8] The six other factors, and the percentage of innovations examined in which they were found to be of importance are: "Top person: the presence of an outstanding person in a position of authority" (25.1%); presence of some other indispensable person, who was of crucial importance due to his or her specialized knowledge (14.7%); "Realization of the potential usefulness of a discovery" (6.2%); "good cooperation" (4.9%); "availability of resources" (8.2%); and "Help from governmental sources, including research associations and public corporations" (5.3%), ([20], p. 69).

be excluded. "Need" was nowhere defined with any precision and, as such, cannot be considered to be identical to market demand.

The study proceeded to consider separately the major and minor innovations, yielding some interesting results. For major innovations, the recognition of a discovery's usefulness was found to be far more important than was true in the total sample (occurring in 14.4 percent of the cases of major technological innovations, the third most prevalent), while "need identification" accounted for only 6.1 percent (tied for fourth place). The relative importance of the two factors was reversed in the minor innovations, as the need factor occured in 18.3 percent and discovery-push was of importance in only 5 percent of the cases, a finding similar to that in the Battelle study's analysis of research events (see below).

Some evidence of a weakly counterfactual variety concerning the factors which distinguish successful and unsuccessful innovations is contained in the analysis of factors which delayed innovation: "These categories refer to delays between an innovation being apparently possible and the Award-winning firm achieving success" ([20], p. 70). Success was nowhere defined but it apparently denotes successful commercial introduction of an innovation. As such, some of these factors refer to the diffusion process.

This analysis of delaying factors is of importance in providing the basis for a more powerful predictive theory of innovation, in that it focusses upon the period between the inauguration of organized research and the commercial introduction of an innovation. The extremely loose treatment of this period in many empirical analyses of innovation, which refer to it as a "lag," renders such analyses distinctly suspect as foundations for policy and prediction. The authors found that the most important factor delaying successful innovation, occurring in 32.5 percent of the cases, was the insufficient development of some other technology: "In many cases an innovation was possible but could not be successfully developed until another technology had 'caught up'" ([20], p. 70). Thus, supply side factors, i.e., technological complementarities, are the most important variables in accounting for the timing of innovations. In 22.5 percent of the cases, there existed at first "no market or need," and the potential of the innovation was not recognized by mangement in 7.6 percent of the cases. Interestingly, when the major and minor innovations were analyzed separately, the "lack of market" and "lack of complementary technology" factors were of equal importance for major innovations, while for minor innovations, the lack of complementary technologies was more important than was the lack of a market. These findings for all of the innovations do little to support the hypothesis that market demand governs the innovation process; were demand the most important influence, one would expect its absence to be of primary importance in explaining delays or failures, which is not the case here.

Four varieties of "linear models" were considered by the authors in a discussion of the explanatory power of simple models for the 84 innovations examined. Under the rubric "discovery push" are placed two models, the first of which, the "science discovers, technology applies" model, is defined as one "in which innovation is seen as the process whereby scientific discoveries are turned into commercial products." The alternative discovery push model is the "technological discovery" one, for "Many innovations are not clearly based on any scientific discovery but can be described as being based on an invention or technological discovery" ([20], p. 73). The first of two heuristic models introduced under the "need pull" category is the "customer need" model, in which the innovation process is described as one "which starts with the realization of a market need. Market research or a direct request for a new product from a customer can be the start of research and development activity . . ." The "management by objective" model was apparently intended as one dealing with more general "mission-oriented" innovation efforts: "Some innovations can be described in terms of the start of the process being a need identified by the management where this need is not a customer need. For example, the need to reduce the costs of a manufacturing process can lead to resources being allocated to research and development . . ." ([20], p. 74). Of course, the "need" on the part of a firm to reduce its own manufacturing costs should be classified as a supply side and not a demand side phenomenon, inasmuch as it has little to do with the market demand for the products of a given firm. While need is still not distinguished from demand the distinction between customer and internal needs is a useful one, the absence of which in many other analyses of factors underlying successful innovations is unfortunate.

Have constructed these heuristic models, the authors conclude that very few of the innovations "fit any one of the above models in a clear and unambiguous manner. The reason for this is quite simple. It is extremely difficult to describe the majority of the cases in terms of a linear sequence with a clearly defined starting point" ([20], p. 71). This statement, with which we are in complete agreement, renders curious the frequent citation of this study as evidence supporting demand-pull theories of innovation (see below).

In focusing upon the factors which stimulated the activity leading to the innovations, a more precise formulation of the Myers and Marquis "design concept" phase, the authors provided some support for the role of demand (whether this implies anything about the nature of the innovation process is quite another issue; focusing upon the motivating factors alone represents a retreat to "black box" theorizing). Even at this remove, however, the authors noted that "it is still very difficult in a large number of cases to state clearly that the innovation is of one type or another" ([20], p. 75). When combinations of the two models in each category were utilized, however, "need pull" was roughly twice as frequent as "discovery push" in the firms' decision to initiate the activities resulting in the innovation. On the other hand it is significant that, for major technological changes the "discovery push" models accounted for seven of the eleven changes so categorized.

It is important to note the restrictiveness of this finding. It is not concerned directly with the factors underlying successful innovation (nor do the authors claim this), but merely the initiation of the search activities leading to the innovation. Since we have no evidence regarding the motivating factors for a sample of unsuccessful innovations, the implications of this finding are not clear; nor, of course, do findings about the motivation for R & D tell one much about the specific characteristics of the outputs from the innovation process. Yet one of the co-authors recently referred to the study as follows: "A study of 84 British technological innovations showed that 'demand pull' occurred more frequently than 'discovery push'" ([20], p. 614). This is a rather strained interpretation of the findings of *Wealth from Knowledge;* it was not "demand", but "need" which was pulling, and the "pull" referred to dealt in fact only with the motivation to commit resources to research and development, not at all with the influences upon the rate and direction of outputs.

HINDSIGHT

The Department of Defense study of the contributions of research to the development of weapons systems, HINDSIGHT,[9] is another empirical analysis often quoted in support of the "demand pull" theories of innovation. However, the study does not consider commercial innovations, so the reliance upon its conclusions in support of the demand-pull hypo-

[9] [26]; see also [40] and [14].

thesis requires the further logical step of equating market demand with Department of Defense "needs"; this point will be discussed further below (certainly, the difficulties of such defense contractors as General Dynamics in selling high-technology products in civilian markets suggests that there are some considerable hurdles to be made in the logical step). In addition, the methodology of HINDSIGHT exhibits failings very similar to those of the other studies reviewed here: a linear model of innovation is imposed retrospectively upon a very complex interactive process; basic and applied research activities are conceptualized as competitive, rather than complementary; and the technological events are arbitrarily assigned identical weights.

In the postwar period, the Department of Defense supported a great deal of research in universities and the private sector; in 1967, some $ 400 million went to research (out of a $ 7 billion R & D budget), of which $ 100 million was basic, "undirected" research and $ 300 million was "applied" in nature. According to its two directors, HINDSIGHT was intended both to "measure the payoff to Defense of its own investments in science and technology", and "to see whether there were some patterns of management that led more frequently than others to usable results... In particular we wanted to determine the relative contributions of the defense and non-defense sectors..." ([40], p. 1571). The development of 20 weapons systems was analyzed by Department of Defense scientists and engineers for HINDSIGHT. The basic methodology was that of benefit-cost analysis; the costs of performing a given military function with the current, recently-developed weapons system were compared with the costs of utilizing the predecessor system, at an equivalent level of effectiveness. The pecuniary savings were attributed directly to the research expenditures incurred in systems development and were found to be substantial. The study concluded that "... the approximately $10 billion of Department of Defense funds expended in the support of science and technology over the period 1946–1962 ... has been paid back many times over" ([40], p. 1575).

In trying to address the second set of issues, those dealing with project management, HINDSIGHT attempted to identify important discoveries or breakthroughs which made possible successful development of the weapons systems. 710 such "Research Events," each consisting of "the occurrence of a novel idea and a subsequent period of activity during which the idea is examined or tested," ([26], p. 139), were identified and classified as Science or Technology Events, according to the evaluators' perceptions of the intentions with which the work leading up to each Event was being carried out.[10]

All Events were weighted identically in assessing the development of these weapons systems, and HINDSIGHT's conclusions regarding the relative importance of mission-oriented versus basic Research Events in weapons systems development have aroused considerable discussion. Only 9 percent of the Events deemed as essential to the development of the weapons systems were found to be Science Events, while 91 percent were Technology Events. Even more important was the finding that of the 9 percent of all Events dubbed Science Events, 97 percent were motivated by a need, only 3 percent arising from "undirected' scientific research. Twenty-seven percent of all of the Events were directed at "a broad class of defense needs not related to a single system or system concept"; 41 percent of all Events were "motivated by a system or system concept in the early or 'advanced development' stage"; and 20 percent of all Events were Technology Events dealing with systems in more advanced stages of development.

In a passage later to be misinterpreted as evidence for the primacy of market demand forces in the innovation process, HINDSIGHT's directors concluded that "... nearly 95 percent of all Events were directed toward a Department of Defense need" ([40], p. 1574). Assuming away the numerous conceptual and methodological difficulties of HINDSIGHT, can this evidence concerning the 20 weapons systems and their development be applied to support the *market* demand-pull hypothesis? In the first place, it is far from clear how this evidence can possibly be related to innovation in a market context; are such authors enthusiastically quoting HINDSIGHT viewing each of 710 Events as individual innovations, or are each of the 20 weapons systems seen as the unit of analysis, the innovations, which were "called forth" by a need? Nowhere is this specified, but certainly individual Research Events are not anything like innovations in a capitalist market context (nor does

10 "Science Events" included mathematical and theoretical studies dealing with natural phenomena, "experimental validation of theory and accumulation of data concerning natural phenomena," and a combination of the above two activities. "Technology Events" included the development of new materials, "Conception and/or demonstration of the capability to perform a specific elementary function, using new or untried concepts, principles, techniques, materials, etc.," and theoretical analyses of properties of materials or equipment ([26], p. 12). The study noted that the definition of "scientific" research was a very rigorous one, and was in fact more restrictive than that employed by the Defense Department ([26], p. 60).

HINDSIGHT claim this for them); rather, they are intermediate steps in solving the larger problem of building a weapons sytem, the desired characteristics of which are well-specified by Department of Defense personnel. To conclude with HINDSIGHT that certain well-specified technical problems in electronics and metallurgy can be solved by research personnel is a distinctly different conclusion from that which portrays market demand as governing the direction and character of innovation.[11]

The view of innovation which is implicit in the study's attempt to assess the direct contributions of basic and applied scientific and technical research, is one which seems to view scientific and technical research as somehow being competitive, rather than complementary, enterprises. Yet, such a view of the innovative process is a very peculiar one, at variance with most accepted "linear' models of innovations. In these formulations of the innovation process, scientific research serves as a foundation for technical research – certainly this is a prominent justification for the Pentagon's funding of university basic research. It is likely that "linear" models of innovation greatly exaggerate the extent to which the flow of ideas and resources from basic to applied research is unidirectional in nature. Nonetheless, the basic research contribution to more applied technical work, in terms both of personnel and information, is crucial. Indeed, in the executive summary of the study's Final Report, a passage apparently overlooked by many of the interpreters of the findings of HINDSIGHT states

> It is emphasized that this study identified only those incremental contributions to existing bodies of scientific and technological knowledge that were utilized in the analyzed military equipments. The strong dependence of these contributions upon the total base of science and technology must be recognized. ([26], p. xv).

Operationally, the resort by HINDSIGHT to an arbitrary cutoff point of 20 years in tracing the important Research Events in weapons development works to underestimate the contribution of basic research activities. Clearly much of the knowledge base which is absolutely essential to the technical breakthroughs in electronics, for example, goes back to the late 19th and early 20th centuries, as the Final Report points out:

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[11] See [29], ch. 3, entitled "The Nonmarket Character of the Weapons Acquisition Process."

> ... less than 16 percent of the technologically oriented R & D Events were traced to a post-1935 science base. The other 84 percent came directly from the application of nineteenth-century unified theory, were the results of empirical research, or appeared as invention not needing scientific explanation ([26], p. 31)

The findings of the study thus do not address the relative importance of basic versus applied research activities, but rather concern the vintage of the scientific knowledge which is utilized in the weapons innovation process. The importance of the basic scientific knowledge base is underlined by the above statement, which also reveals the sensitivity of the study's findings to the definition of the time horizon for Research Events, and the care with which these findings must be interpreted.

The notion in HINDSIGHT that breakthroughs which cumulated in a new weapons system can simply be "added up" overlooks the great variation in the importance of individual Research Events. This flaw is not unique to HINDSIGHT, but it serves to bias the findings against the importance of Science Events, given the often-greater importance of basic research findings, due to their wide applicability and radical nature. The HINDSIGHT schema also views each innovation as a logical outcome of an accumulation of technical breakthroughs consciously directed toward a single end; yet this is belied by a glance at many of the case studies compiled by the project. In many cases, significant findings resulted from work on a completely unrelated project; yet the study takes all "mission-oriented" events as directed toward the particular weapons system under examination in the case study. The approach also ignores the great uncertainties inherent in the innovation process, the numerous dead ends and unsuccessful Research Events – what proportion of all of the mission-oriented research projects failed, and how does this compare with the basic scientific research projects? Nowhere does HINDSIGHT address these issues – again, we have a study dealing only with successful innovations, in this case, successful "Research Events."

TRACES and BATTELLE

TRACES (Technology in Retrospect and Critical Events in Science) [10] and the Battelle Research Institute study on the *Interactions of Science and Technology in the Innovative Process* [4] are broadly similar analyses of a few innovations, adopting a lengthier time horizon and focusing more upon the early phases of the innovation process than was the case in HINDSIGHT. These studies share with HINDSIGHT a concern with the contributions to innovation of basic and applied research, as well as a methodology of examining identifiable "events" in the innovation process .(indeed, many observers have portrayed these studies, commissioned by the National Science Foundation, as responses to HINDSIGHT). The use of a lengthier time horizon in these studies yields a more reasonable view of basic and applied research activities as complements, rather than substitutes, in the innovation process. The Battelle study represents a more ambitious effort to analyze the relative importance of research events, as well as the factors influencing these events; while TRACES made no reference at all to the relative importance of "demand-pull" or "technology-push" in the innovation process, the Battelle study did attempt to analyze such factors.

TRACES is a collection of reconstruction of the key research events involved in each of five innovations: magnetic ferrites, the video tape recorder, oral contraceptives, the electron miscroscope, and matrix isolation. The study was intended to "provide more specific information on the role of various mechanisms, institutions, and types of R & D activity required for successful innovation" ([18], p. ii).

The retrospective tracing of the innovation events (not, it should be noted, the underlying *processes*) for each of the five innovations was performed by scientific and technical experts; only the most important events, defined as "the point at which a published paper, presentation, or reference to the research is made" ([18], p. 2), were included. Once identified, research events were classified on the basis of their "technical content or motivation," in a fashion similar to the procedure followed in HINDSIGHT. No attempt was made to weight differentially the research events according to their importance, which again is a technical limitation shared with HINDSIGHT. Unlike the HINDSIGHT study, no distinction was drawn between "scientific" and "technological" research events and activities. Three categories of general R & D activity were considered in the study: nonmission research, "motivated by the search for knowledge and scientific understanding without special regard for its application"; mission-oriented research, "performed to develop information for a specific application concept prior to development of a prototype product or engineering design"; and development and application, "involving prototype development and engineering directed toward the demonstration of a specific product or process for purposes of marketing" ([18], p. ix).

As we have seen in the case of HINDSIGHT, the definition of the time horizon for each innovation examined is crucial in this "reconstructive" methodology. The time horizon adopted in TRACES is one which places far more emphasis upon the development of the scientific knowledge base, and much less upon the phase of modification and refinement for commercial sale. The definition of the origins of an innovation is extremely elastic, but it does exclude the diffusion process from the history of a given innovation.

The conclusions of the TRACES study present an interesting (if not surprising) contrast to those of HINDSIGHT. Some 341 research events were identified; of these, some 70 percent were mission-oriented, "nonmission-oriented" variety, while 20 percent were mission-oriented, and 10 percent were in the development category. The contrast with the conclusions of HINDSIGHT is due in part to the finding of TRACES that 45 percent of the nonmission research underlying an innovation was completed at least 30 years in advance of the innovation, and thus excluded *a priori* from consideration in HINDSIGHT, and the study's findings that 80 percent of nonmission research is completed fifteen years before the innovation.

TRACES dealt primarily with the contributions of basic or applied research to innovation, the central issue raised in HINDSIGHT. The Battelle study on the other hand was commissioned by NSF as an extension of TRACES, and was designed to deal with a broader range of issues (including those considered by Myers and Marquis). In addition, an effort was made in the Battelle study to rank research events by importance. The study re-examined three of the five innovations which had been analyzed by TRACES (magnetic ferrites, oral contraceptives, and the video tape recorder), and considered an additional five: heart pacemakers, hybrid grains, xerography, input-output economic analysis, and organophosphoric insecticides. Research events were identified by scientific and technical personnel as before, with the additional technique of oral interviews being utilized extensively. As in TRACES, the three categories of nonmission, mission-oriented, and development events were utilized in the categorization.

The important differences between TRACES and the Battelle study arise in three areas. As was mentioned above, the Battelle study attempted to distinguish the subset of "decisive" events from "significant" events in the innovation processes considered. Significant events are essentially identical, in definition and dating, to the key events of TRACES, a significant event being defined as "an occurrence judged by the investigator to encapsulate an important activity in the history of an innovation or its further improvement, as reported in publications, presentations, or references to research." A decisive event "provides a major and essential impetus to the innovation. It often occurs at the convergence of several streams of activity. In judging an event to be decisive, one should be convinced that, without it, the innovation would not have occurred, or would have been seriously delayed" ([4], p. 22).

A second major difference is the analysis contained in the Battelle study of the influence of some 21 factors upon decisive events, as well as an attempt to define certain characteristics of the overall process of innovation in each of the eight cases considered. Among the 21 factors are Myers and Marquis' "motivational factors," *viz.*, "recognition of scientific opportunity," "recognition of technical opportunity," and "recognition of the need," as well as managerial, external and peergroup influences. Nowhere did the Battelle study specifically identify the ways in which these various categories influence decisive events – in their analysis of these motivational factors, Myers and Marquis were speaking only of the motivation for a single firm to undertake a particular R & D project, rather than of factors motivating specific scientific or technical discoveries. In addition, the Battelle study utilized a chronological framework which weighted the final development phase more heavily; this difference with TRACES is not mentioned explicitly but emerges from a comparison of the chronologies in the two studies for similar innovations. The sensitivity of the findings of each study to these different approaches underlines forcefully the difficulty of finding objective truths in this area.

A total of 533 significant events were identified in the Battelle study, of which 89 (17%) were judged to be decisive. Of the 21 factors adduced as influential in the innovation process, "recognition of technical opportunity" and "recognition of need," were the most important for the decisive events, occurring for 89 percent and 69 percent respectively (managerial and funding influences followed these in importance). The finding concerning need recognition for these individual events is difficult to interpret, but it does not seem to support the "market demand-pull" hypothesis, concerned as this study is with individual events in the overall process rather than the motives inducing a single firm to undertake a particular R & D project. The authors of the Battelle study assessed their findings rather differently, however: "Other studies of innovation have shown that innovations are most frequently responsive to the force of 'market pull,' that is, to a recognized consumer need of demand. This observation is broadly confirmed in the present study, even though the ratings cover individual decisive events, rather than the innovation as a whole" ([4], p. 3-1). If need recognition plays such an important role in structuring individual events in the innovation process, this probably reflects the importance of technical complementarities acting as focusing devices, rather than anything like the importance of a market demand for a research breakthrough. The research breakthrough *per se* is not generally marketed, but contributes to an innovation which may be sold commercially.

Problems also arise in the Battelle study's overall characterization of the case studies for each of the innovations. Again, there is nowhere a clear specification of where or how these characteristics enter the process. The study concluded that "in nine of the ten innovations studied (hybrid grains were counted as three innovations: corn, wheat, and rice) recognition of the need for the innovation preceded the availability of means to satisfy that need. This finding supports several previous studies of the innovative process..." ([4], p. 4.6). However, this conclusion is as empty of meaning as many of those reached by the other studies. Can one seriously maintain that the "need" for high-yield grains, oral contraceptives, or a heart pacemaker has been unrecognized for the past centuries? In any case, of what possible explanatory relevance is the temporal priority of the "recognition of the need for the innovation?"

The Battelle study's findings regarding the importance of the three categories of research in producing significant and decisive events differ somewhat from those of TRACES, reflecting the arbitrary beginning date and the slightly different emphasis in each of the retrospective case studies. Nonmission-oriented research accounted for 34 percent, mission-oriented research was responsible for 38 percent, and development for 26 percent, of the significant events. Moreover, when the analysis was confined to the decisive events, the study concludes that only 15 percent arose out of nonmission-oriented research, compared with 45 percent and 39 percent respectively for mission-oriented and development activities:

> Presumably, this fact reflects the tendency for decisive events to occur within or close to the innovative period. Events that occurred at times long preceding the innovation period might have occured some years later without delay to the date of first conception or first realization of the innovation. Such events, often in the realm of NMOR

(nonmission-oriented research) therefore cannot be considered, in retrospect, decisive at the time of the innovation" ([4], p. 4-8).

Gibbons and Johnson

It is worth introducing here the results of a different approach to the retrospective evaluation of innovation and the contributions to it of basic and applied research. Gibbons and Johnston [11] undertook an analysis of thirty innovations which focused upon the origins and character of informational inputs used to solve technical problems in the innovation process. This approach to analyzing the contributions of in-house or external research, as well as basic and applied research, conceptualizes technical problem-solving as based largely upon the exchange of information. The authors maintained that their study "has avoided any attempt to trace the origins of a piece of hardware to either science or technology" ([11], p. 230). This contrasts with the methodology of the HINDSIGHT, TRACES, and Battelle studies.

Gibbons and Johnston classified information inputs as scientific or technical by the source, rather than the content, of such information. This poses at least one possible problem, inasmuch as purely technical information may be transmitted through papers published in scientific, rather than technical journals. An additional methodological difficulty exists in the authors' efforts to establish the age of the information inputs used in the innovations. If the lag between discovery and publication is significant and varies among different kinds of knowledge, analyzing the timing of the application of scientific work to innovation through examining the published work is likely to yield deceptive results.

Nevertheless, the conclusions of Gibbons and Johnston are potentially very significant in improving our understanding of the complex role of science in the innovation process. They found that scientific information made a significant contribution to the innovations. Thirty-six percent of externally-obtained information, and 20 percent of all information, utilized in the innovation processes examined was scientific in character; the information of greatest utility in solving technical problems was drawn from scientific journals. Personal contacts with scientists from outside the firms (usually from universities or government research establishments) were found to yield very useful information, not only about theories and properties of materials, but of a more directly useful, "applied" variety, concerning the availability of specialized equipment or suggesting alternate designs. In many cases, university scientists aided firms as a sort of "gatekeeper," "'translating' information from scientific journals into a form meaningful to the 'problem-solver'" ([11], p. 236). University-educated personnel within the firm were able to contribute substantially to the problem-solving process due to their greater use of external scientific information sources, in the form of journals or acquaintances at universities.

Gibbons and Johnston concluded from their analysis of information flows that the interactions between basic and applied, in-house and external, research are so complex that normative criteria for the optimal direction and size of government research support are not easily discerned. They also concluded that the basic research infrastructure in universities and governmental installations contributes to commercial innovation in ways other than simply providing the private firm with exploitable scientific discoveries. Thus a complex, nonlinear relationship between basic and applied research is indicated by Gibbons and Johnston's work, far more than is the case in HINDSIGHT. Freeing the analysis of innovations of the restrictions imposed by a Procrustean focus upon "events" thus allows for recognition of a more complex interrelationship between innovation and basic research.

Carter and Williams

C.F. Carter and B.R. Williams [5, 6] carried out an extensive study of innovation decisions of British firms for the Board of Trade, in an effort to illuminate the factors which aid or hinder the application to industrial products and processes of scientific research. As the subtitle of *Industry and Technical Progress* suggests, the basic conceptual schema in their first study is very much a linear model of the innovation process. The discussion in *Industry and Technical Progress* is concerned with the stages in the generation and application of scientific knowledge, from basic research to the point of substantial investment in the commercial production of an innovation, as well as the managerial and economic factors which facilitate the application of such knowledge on the part of private firms. The central concern of *Investment in Innovation*, published subsequently, is the specific factors influencing the decisions of firms to invest in new technologies. One major difficulty in the analyses carried out by the authors is that of distinguishing the factors governing the diffusion of an existing innovation from those influencing the development of a new one.

The methodology utilized in the Carter and Williams studies was that of extensive field interviews and case studies. In-depth studies of 152 firms were carried out through interviews and questionnaires, covering a wide range of firm characteristics, including information on executives and research personnel, firm size and product range, and communications patterns within firms. The knowledge base underlying each firm's industry was also reviewed to gain an appreciation of the potential for innovation within each industry. In addition, a small sample of firms in each of four industries – paper, pottery, jute, and cutlery – and equipment suppliers in each was examined in order to provide a more intensive study of the innovation process. Five specific innovations, in pottery, building, metals and machinery were also studied to provide an understanding of the transition from invention to diffusion.

The authors were reluctant to impose a highly-structured model of the innovation process upon their data; rather, they chose simply to report the results of their extensive surveys. The authors concluded that explicit consideration of market demand factors is rare in decisions concerning the level of investment in research and development. This was due to an absence of clearly-defined corporate objectives, and a focus upon short-term development and survival. Yet one certainly would expect consideration of market demand to be of great importance in the firm's allocation of resources to research and development if the market demand factors are crucial in affecting the direction of innovation. The findings, therefore, are not supportive of the demand-pull hypothesis. Evidence of a slightly different nature, concerning the origins of specific R & D projects, is presented by the authors for slightly less than one-third of 200 innovations examined. They found roughly 25 percent of the innovations originated in a firm's R & D laboratory, 18 percent began from the prediction that a future market existed for a particular product, and 10 percent of the innovations each were contributed by the demands of sales departments and production departments for solutions for immediate problems. Such evidence of course deals only with the inception of research and, additionally, the forecast "need for an innovation," strictly speaking, does not imply an increased market demand. Profit-seeking firms are most unlikely ever to proceed in the *absence* of some anticipated "need."

Evidence concerning the conditions influencing the commercial success of an invention is found in both *Industry and Technical Progress* and *Investment in Innovation*. The precise nature of the dependent variable in these surveys is not made very clear; is it diffusion, or simply the development of an invention to the point of commercial feasibility? In *Industry and Technical Progress*, the firm's decisions to proceed with development were examined in 250 cases:

> In sixty-five cases (fifty-three involving the introduction of a new product differing markedly from the normal range) the firms were induced to proceed by the conviction that the potential market was large. In fifty-four cases improvement in quality of product was thought to improve the competitive position of the firm. In sixty-nine cases the expectation of a saving in process cost was a sufficient motive. In thirty-five cases the fact that there was a 'significant innovation' was thought to be in itself a sufficient reason for going ahead. In eighteen cases the innovation, by broadening the basis of the firm's operations, was thought to improve the prospects of long-term stability; in sixteen cases innovations were intended to guarantee supplies of materials; in ten cases 'government interest' made the project seem worthwhile. In thirteen cases the fact that the innovation 'increased output' was a sufficient incentive... ([5], p. 85)

Here one finds that "potential demand" was the primary factor in only slightly more than one-quarter of the cases, even under the fairly elastic definition set forth.

Investment in Innovation examined the investment decisions of business firms which underlay the diffusion of new technologies. In a sample of 204 innovations, "just over a half . . . were ascribed by the firms concerned to definite causes, such as the pressure of competition or of excess demand" ([6], p. 57). Of these, 18 percent were adopted out of a desire to overcome shortages of materials or labor; "desire to meet excess demand" accounted for 10 percent; "demands by customers for new types or qualities of product" was responsible for 12 percent; "desire to use the work of research and development departments" occurred in 18 percent; "Direct pressure of competition" accounted for 10 percent; and "successful trials of product or process in other industries of in other countries" explained 33 percent of the events. Finally, the authors distinguished between "active" and "passive" innovative decisions:

> In making a *passive* innovation the firm is responding to direct market pressure, as shown by excess demand or by developing competition and falling profit margins... In making an *active* innovation the firm is deliberately searching for new markets and techniques, even though there may be no direct market pressure to do so ([6], pp. 57–58)

It seems clear that only a subset of the passive innovations developed by a firm can be viewed as "called forth" by market demand. Carter and

Williams' finding that 60 percent of the 204 innovations considered are of the active variety is therefore of interest.

The Carter and Williams study exhibits few of the methodological problems of the other studies considered here; this is largely due to the lack of a well-specified analytic framework and the (perhaps understandable) reluctance to draw strong general conclusions from the study. Particularly troublesome is the recurrent fuzziness about precisely what aspect of the innovation process is being considered in a given set of surveys. In only one set of survey results, the study of the departmental origins of research and development projects, do we find support for the primacy of market demand forces in the innovation process. This study provides some rather weak evidence supporting the view that market or customer needs serve to influence the direction of entrepreneurs' innovative efforts. We certainly do not deny this. It is the identification of "needs" with "market demand", and the dominant role in commercial innovation ascribed to this amorphous variable, which we criticize. As has been noted elsewhere, however, evidence concerning the *origins* of R & D projects is of limited relevance to attempts to understand the rate and direction of innovation. Much of the other evidence set forth by the authors either does not deal with the innovation process *per se*, or does not afford any support for a demand-pull position, or both.

Baker et al.

The studies by Baker, Siegman and colleagues [2, 3] provide perhaps the most dubious collection of evidence concerning influences on the innovation process. The first paper, by far the more widely quoted of the two, is concerned with the more general phenomenon of idea generation within organizations, using a corporate research laboratory as the object of study: "... we are concerned with identifying organizational factors which aid or deter idea creation, and with describing how a set of ideas was created in one large industrial R & D laboratory" ([2], p. 157). One of the authors defined an idea as "an actual or potential proposal for undertaking new technical work which will require the commitment of significant organizational resources..." ([2], p. 158). The object of study is thus only tangentially related to the innovation process; all that is considered is the very preliminary phase of project proposal. The decision as to which ideas merit further development, the direction and character of the subsequent research process, and the commercial introduction of an innovation, are all excluded from the purview of this article.

The authors attended meetings of "idea generation groups" (IGG's) at a corporate research laboratory, in the role of silent observers and note-takers. The ideas put forth by the research group were rated on a numerical scale, and the 5 to 10 "best" ideas submitted by the group were chosen by the participants in the idea generation group. Nowhere are the criteria, upon which these ratings were based, made explicit – nor is any effort made to distinguish subsequently successful ideas from unsuccessful ones. A set of "stimulating events" (e.g., "thinking by self," "interaction with other persons") was identified and ideas classified accordingly; in addition, "the nature of the problems which stimulated the ideas" ([2], p. 159), was considered. "Need events" were defined as "recognition of an organizational need, problem or opportunity", and were identified for 94 percent of the ideas developed; "means events," defined as "recognition of a means or technique by which to satisfy the need, solve the problem, or capitalize on the opportunity," occurred for 92 percent of the ideas. Two "patterns of idea-generation behavior" were also identified, "need–means" and "means–need," referring to the sequence of the above two events in the generation of ideas. Seventy-five percent of the ideas, and 85 percent of those subjectively rated as the best ideas, were categorized as arising from "need–means" sequences, while 25 percent resulted from the converse sequence.

In a subsequent article, "The Relationship Between Certain Characteristics of Industrial Research Proposals and Their Subsequent Disposition", the authors extended their analysis of idea generation to include the phase in which a choice among the ideas produced by the IGG is made. The authors found that urgency, defined as "Immediacy of the need, problem, or opportunity toward which the idea is directed" ([3], p. 119) was positively correlated with a subsequent affirmative decision to proceed with the research project. Again, however, "need" is very broadly defined, and the decision to proceed with research tells one little about the successful or unsuccesful development of an innovation.

Interpreting the findings of these studies as supportive of the "market demand-pull" hypothesis seems very strained; although others have done so, the authors of the articles made no such claims. Their definition of "needs" is extremely broad, and overlaps with the concept of market demand to only a limited extent. Taken together, the articles do address the nature of the stimuli to undertake research; this represents a small part of the overall innovation process, however, and the subsequent technical and/or commercial success or failure of the innovation is not considered in such a framework.

SAPPHO and FIP

A final pair of studies is noteworthy for their attempts to compare directly successes and failures in innovation. Both SAPPHO (Scientific Activity Predictor from Patterns with Heuristic Origins), from the Science Policy Research Unit at the University of Sussex, and FIP (Falk Innovation Project), from the Falk Institute for Economic Research in Jerusalem, compare innovations which failed either before (i.e., research is terminated) or following introduction.[12] The success criterion thus deals more with commercial diffusion than with the innovation process *per se*. In interpreting the conclusions of the studies, therefore, it is important to note that their central subject is not the factors which motivate the processes leading to successful or unsuccessful innovations, nor is it the character of the innovation process itself. In addition, the fact that both studies focus upon innovation within one or two industries implies that the scientific and technical knowledge base upon which the firms under examination may draw is fairly *homogeneous*, and "technology-push" factors are therefore likely to be excluded *a priori*.

The two studies differ in that "while SAPPHO is basically a study of the management of innovation, FIP is an attempt at identifying comparative advantage in innovation" ([35], p. 2). Thus, while SAPPHO performed pairwise comparisons of commercially successful and unsuccessful innovations within two industries (chemicals and scientific instruments), with an eye to identifying characteristics differentiating the members of each pair, FIP attempted to focus upon features of market and producers' structures which would explain the pattern of success and failure for a whole range of innovations within a single industry (electronic medical instruments). The FIP study thus subsumes considerations of project selection, as well as project management. Both studies contain some extremely useful analyses of the influence of marketing factors upon commercial success in innovation, and as such represent important refinements in the theory of demand-induced innovation.

Forty-three pairs of innovations in chemicals and scientific instruments were analyzed in the course of SAPPHO, drawing upon extensive inter-

[12] R. Rothwell, C. Freeman, A. Horlsey, V.T.P. Jervis, A.B. Robertson, and J. Townsend [34 (SAPPHO)]; M. Teubal, N. Arnon, and M. Trachtenberg [43 (FIP)]; and R. Rothwell, J. Townsend, M. Teubal and P.T. Speller [35 (SAPPHO/FIP)].

views and technical analyses. In the first phase of the study, the analysis was confined to assessing the importance of 24 variables in a strictly pairwise manner, comparing commercially successful innovations with unsuccessful ones. No broader ranking of all of the innovations examined, whether in terms of their importance or degree of success, was undertaken. Subsequently, an analysis of groups of innovations was carried out in an effort to focus upon the variables influencing the degree of commercial success. Five categories of variables were found to be most important in distinguishing successes from failures:

(1) Successful innovators were seen to have a much better understanding of user needs.
(2) Successful innovators paid more attention to marketing and publicity.
(3) Successful innovators performed their development work more efficiently than failures but not necessarily more quickly.
(4) Successful innovators made more use of outside technology and scientific advice, not necessarily in general but in the specific area concerned.
(5) The responsible individuals behind the successful innovations were usually more senior and had greater authority than their counterparts in unsuccessful projects ([34], pp. 285–286).

Some interesting contrasts between the chemicals and instrument industries also emerged in the explanation of success and failure. The chemicals innovations were predominantly process innovations developed by very large firms; the influence of individuals was less important, as was the understanding of user needs, than was true in the instruments industry, characterized by small firms and product innovations.[13] Lead times, i.e., being the first with a new product or process, were quite important in chemical industry innovations, which frequently were quite radical changes, while, in instruments, the first firm to introduce an innovation failed more often than did the second innovator. These inter-industry differences are a central aspect of the FIP and SAPPHO/FIP studies.

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[13] A recent series of papers by von Hippel concerning innovation in the American scientific instruments industry emphasizes the active role of instrument users as originators of innovations. Von Hippel's work underlines the importance of "user needs" in successful product innovation, but his studies do not support a "market demand pull" hypothesis for innovation. Instead, they tend to highlight the importance of the distinction between "needs," which may arise from any source, and for any reason, and market demand, which is perforce mediated through a market. The "needs" to which innovative instrument users are responding are in very few cases equivalent to consumer demands transmitted through the market. See [47] and [48].

A brief discussion in SAPPHO of the motivation for innovations concluded that "Of the 43 pairs studied, in 21 percent 'need-pull' differentiated in favor of success: in the remaining 79 percent there was no correlation between success and failure and motivation: in no case did technology-push differentiate in favour of success, or need-pull in favor of failure" ([34], p. 277). The definitions of "need-pull" and "technology push" are not reproduced in the article. It is again worth noting the similarity of technologies in most of the pairs of innovations studied, a methodological aspect which may have biased the results of the analyses against "technology-push" explanations.

The FIP study did not proceed with a strict pairwise comparison of innovations, but rather focussed upon the performance of R & D programs of nine firms in a single industry, biomedical electronics. Among the variables examined were so-called "area variables," characteristics of firm structure and market demand in the industry. This set of influences was not examined in SAPPHO; however, most of the other variables considered in the analysis of success and failure in the FIP study were analogous to those utilized in SAPPHO. Also similar to SAPPHO was the definition of success, which was simply commercial success. The FIP study examined the number of successful and unsuccessful research projects within each of these nine R & D programs; despite the rejection of the SAPPHO pairwise approach in favor of a more comprehensive, intra-industry analysis, no ranking of the extent of success or failure was attempted.

The study concluded, as did SAPPHO, that sensitivity to user needs was of great importance in explaining the success of research projects. One piece of evidence adduced in support of this position stated that "The proportion of failures in programs whose idea originated in R & D exceeds the proportion of failures in other programs" ([43], p. 18), which obviously requires an assumption about the relative sensitivity of a firm's various units to "user needs." The same caveats concerning the definition of success, and similarity of underlying technologies, which were noted for SAPPHO, apply here as well. Of particular interest in the FIP study's discussion of market demand, however, is the concept of "market determinateness," one of the exogenous variables in the study: "Market determinateness refers to the degree of specificity of the market signals received by the innovating firm and consequently to the extent to which it anticipates (instead of responding to) demand" ([43], p. 20). The similarity between the firm behavior implied by this definition, and the Carter and Williams concept of active and passive innovative firms is interesting, and may reinforce the contention that only the passive firms really fit the "demand-pull" paradigm. In all of the extensive discussions of the role of demand in the innovative process which have been surveyed here, this concept stands out as a useful one for comparing the role and importance of "demand-pull" forces in different industries, something which cannot be done merely using the broad, fuzzy concepts of "user needs" or "need recognition." Comparing all of the R & D programs within the biomedical electronics industry, the FIP study concluded that "The degree of market determinateness differentiates sharply between the successful and unsuccessful biomedical electronics R & D programs studies " ([43], p. 31).

In a comparison of the FIP and SAPPHO studies, it was concluded that an important inter-industry explanatory variable lay in this area of "market determinateness":

> Most of the SAPPHO chemical innovations were process innovations not involving fundamental changes in existing products while most instrument innovations involved a significant new-product component. This suggests that the chemical innovations were more market determinate than the instrument innovations, which may in turn explain the greater effort required to understand user needs and the correspondingly greater need for external communications in the instrument industry. ([35], p. 11).

The analysis of innovation failure thus yields rather useful insights, particularly this last concept of market determinateness, a concept which affords a means of examining and comparing innovational performance at a somewhat higher level of aggregation than do most of the "demand-pull" approaches to the problem. However, neither SAPPHO nor FIP focus narrowly upon successful innovation *per se*, but include in the definition of success much that more appropriately should be seen as relating to the diffusion of innovations; the support afforded by these studies for "market demand-pull" explanations of innovation is thus distinctly limited.

INTERPRETATIONS OF THE STUDIES

A major reason for surveying the empirical studies of innovation is the widespread acceptance of the conclusions or, at least, the frequent appeals to the findings of these studies in support of "demand-pull" positions. As was pointed out repeatedly in the review above, most of these studies say rather little about the influence of market demand upon the rate and direction of innovative output. However, even the limited conclusions of the studies are frequently distorted and misquoted. A sampling of the secondary and review literature is discussed below to show the extent of the haphazard reliance upon these studies. Much of the problem derives from the fact that the quoted studies differ widely in the nature of the dependent variable which is being explained, and often deal with very different phases of the innovation process.

Myers and Marquis' empirical study contains a brief summary of four other studies which, they argued, supported their conclusion that "demand recognition" is the driving force in the innovation process. Three of the studies, Carter and Williams, HINDSIGHT, and the first article by Baker et al., were reviewed above. The authors compare their findings on the influences which motivate firms to undertake R & D projects with the findings of Carter and Williams, published in *Investment in Innovation* (not *Industry and Technical Progress,* incorrectly referred to by Myers and Marquis as the source), concerning a much broader range of investment behavior. As was noted above, a central focus of *Investment in Innovation* is the influences upon the diffusion process and adoption decisions of firms, not simply the factors motivating research; these latter factors are discussed in *Industry and Technical Progress.*

Myers and Marquis also discussed the Carter and Williams categories of "active" and "passive" innovating firms, without stating in what fashion these findings of *Investment in Innovation* support the "demand-pull" position.[14] As was discussed above, however, the empirical results of the active/passive distinction do not strongly support the primacy of "demand-pull" influences upon innovation. The authors cited the first study by Baker et al. as support for their position, despite the fact that the Baker study does not even deal with commercial innovation, but rather with the very different subject of idea generation. The interpretation of HINDSIGHT set forth by Myers and Marquis also ignores the fact that the HINDSIGHT study examines Research Events, rather than innovations, and the objects of study have little to do with innovation in a market context.

A recent review article by J.M. Utterback in *Science* draws upon eight empirical studies of innovation, five of which were reviewed above,[15] in stating that

14 "Active innovating firms produce most of the innovation studied" ([23], p. 33).

15 [46]. The five studies reviewed above to which Utterback refers are [3], [20], [5], [34] and [26].

> 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 ... There is a striking similarity between the findings of studies conducted in the United States and those conducted in the United Kingdom. ([46], p. 621).

SAPPHO, however, really deals with the conditions underlying commercial success of innovations, while the Langrish study provides some support for "need-pull" only as a motivating influence, and rejects simplistic, linear models of innovation explicitly. Utterback nowhere made clear what specific aspect of the innovation process he was addressing, an omission of importance because of the differing foci of the empirical studies which he quotes. In addition, the equation of "market factors," "market demands," and "needs," implies an unacceptably loose definition of market demand and "demand-pull." The problems of using HINDSIGHT and the Baker study as support for Utterback's contention have already been discussed.

Carter and Williams' *Industry and Technical Progress* is referred to by Utterback as having shown 73 percent of 137 innovations to have been stimulated by "market, mission, or production needs," while 27 percent arose from "technical opportunities." In fact, nowhere in *Industry and Technical Progress* does there appear such a result for an analysis of 137 innovations. However, the authors' examination of "the passage from invention to innovation in over 250 cases of product or process development" concludes that 188 instances, 75 percent, resulted from the "expectation of a saving in process cost," "the conviction that the potential market was large," or improvement in the "competitive position of the firm" ([5], p. 85). Again, the connection of these factors with shifts in market demand is far from obvious and the phase of the innovation process discussed is not that of the initial decision to proceed with R & D. Myers and Marquis' study and that by Langrish et al. are also relied upon for empirical support by Utterback. The conclusions of both studies concern the motivation for innovation, although in both studies, as we have seen, the distinction between need and market demand never is drawn sufficiently sharply to provide unambigous support for Utterback's position.

A recent study of the evidence on *Technology, Economic Growth and International Competitiveness* by Robert Gilpin [12] contains a strong endorsement of the "market demand-pull" approach to innovation as a basis for government policy "to stimulate the technological innovations and industrial productivity required to help meet international economic competition, stimulate economic growth, and solve our domestic problems" ([12], p. 1). Although Gilpin's position apparently relies upon the evidence from the studies reviewed here, he does not quote any of them, preferring instead the sweeping assertion that

> Everything that we know about technological innovation points to the fact that user or market demand is the primary determinant of successful innovation. What is important is what consumers or producers need or want rather than the availability of technological options. Technological advance may be the necessary condition for technological innovation and on occasion new technology may create its own demand but in general and in the short-run, the sufficient condition for success is the structure or nature of demand. ([12], p. 65).

This statement is an extreme version of "demand-pull," and in fact contradicts Gilpin's own earlier statement that "successful innovation involves increasingly a *coupling* or *matching* of new science and technology with market demand" ([12], p. 37), a statement implying that demand is necessary, but not sufficient. This confusion of necessity and sufficiency is really at the heart of much of the controversy over the role of demand in innovation. Gilpin further strikingly qualifies the statement by admitting that "This emphasis upon market demand as a stimulant to innovation must be qualified with respect to innovation in one area of economic goods, that is consumer goods and services" ([12], p. 38). In other words, "everything we know about technological innovation" in fact relates to a rather specialized subset of economic sectors, the more so since military and space industries cannot be said to exist in a conventional market environment. Needless to say, this is rather a substantial "qualification"! As if this were not sufficient qualification to his sweeping assertions about the primacy of market demand, Gilpin also concedes that radically new technologies can and do create their own markets. "Certainly this has been the case with such radical innovations as the computer, the laser, and nuclear power" ([12], p. 37). One is reminded of Schumpeter's observation about Malthus: that the most interesting aspect of his theory of population were the qualifications.

The only piece of empirical work on the role of demand-side forces in innovation which Gilpin explicitly discusses is *Invention and Economic Growth* by Jacob Schmookler: "Schmookler demonstrated that the primary factor in successful innovation was market demand" ([12],

p. 37). This statement represents an illegitimate extension of Schmookler's findings, and reflects the confusion and ambiguity over the precise nature of the dependent variable mentioned above. Schmookler's work deals with invention, *not* commercially successful innovations; thus his use of patent statistics as a measure of inventive output. Rather than explaining the factors underlying commercially successful innovations, Schmookler analyzed market demand forces as they influenced shifts in the allocation of resources to inventive activity -- an entirely different matter. Gilpin is at once more and less careful in his interpretation of the evidence than others discussed here. While he refers only to market demand factors in his discussion, which presumably is the restrictive set of influences dealt with by economists, Gilpin nowhere makes clear the fact that these many studies of the innovation process rarely refer to narrowly defined market demand as the crucial motivation.

CONCLUSION

A general critique and discussion of the empirical studies reviewed above is undertaken in this section. The studies may be criticized at the specific level of failing to substantiate their hypotheses; the primacy of market demand forces within the innovation process is simply not demonstrated. At a more general level, however, the weaknesses of the broad conceptual framework of the studies become clear; the uncritical appeal to market demand as the governing influence in the innovation process simply does not yield useful insights into the complexities of that process. A brief discussion of some possible policy implications of these issues concludes the paper.

A major difficulty exists in the interpretation of the results of these empirical studies, in that they vary widely in the nature of the dependent variable being considered, and their conclusions, even assuming they were well-supported, therefore do not supply uniform support for a demand-pull argument. Myers and Marquis, Baker et al. and Langrish et al. deal with the motivations for the allocation of R & D inputs by a single firm in their conclusions supporting demand-pull theories of innovation. TRACES, HINDSIGHT, and the Battelle study all focus upon the lengthy histories of specific innovations, each of which involves numerous individuals, commercial and noncommercial laboratories, and firms. The "demand-pull" conclusions of these studies concern events *within* the process resulting in a given innovation, in numerous different institutional settings, rather than a single firm's decisions concerning the commitment of resources to particular projects. In addition, HINDSIGHT deals with the innovation process in a nonmarket environment, one in which commercial feasibility and market demand are concepts shorn of their usual meaning. The conclusions of the SAPPHO and FIP studies deal primarily with the factors influencing the commercial success of an innovation following the production of a prototype, again approaching the phenomenon at the level of the individual firm.

In order to retain its analytic content, market demand must be clearly distinguished from the potentially limitless set of human needs. Demand, as expressed in and mediated through the marketplace, is a precise concept, denoting a systematic relationship between prices and quantities, one devolving from the constellation of consumer preferences and incomes. To be taken seriously, demand-pull hypotheses must base themselves upon this precise concept, and not the rather shapeless and elusive notion of "needs." Yet most of these empirical studies rarely, if ever, make such a distinction, as a result of which the relationship of the "need recognition" category to market demand as a motivating or controlling influence in the innovation process is tenuous indeed. An additional consequence of this confounding of need and market demand is the frequent failure to distinguish between motivations or influences upon the innovation process which arise from within the economic unit, such as those resulting from increases in output or changes in production technology, from factors which are external to the firm and mediated by the market. Examples of this are the treatment by Myers and Marquis, as well as Utterback (in his interpretation of Carter and Williams' findings) of "production needs," which are internal to the firm, as equivalent to shifts in the market demand for a firm's products. Also of importance is the fact that all of the studies which attempted to rank innovations or research events by the importance of these occurrences found that the most radical or fundamental ones were those least responsive to "needs." Even within the flawed conceptual and methodological framework of these empirical studies, then, the "demand-pull" case is admittedly weakest for the most significant innovations. Does an explanatory schema retain much usefulness when it is contradicted by the most important occurrences in the set of events which it purports to illuminate?

The working definition of market demand employed in many of the empirical studies examining the individual firm's decisions in the innovation process is one which excludes only the most economically irrational set of decisions; i.e., market demand becomes identified with *all* those price signals transmitted through the marketplace which provide the basis for rational economic decisions. The definitions of "technology-push" employed by Myers and Marquis imply that only cases in which absolutely no attention is paid to the economic return likely to result from an innovation can be considered as instances in which a "technological push" caused the innovation. Yet, in a capitalist economy, where decisionmakers operate on the basis of expectations of future profit, no substantial innovation activity will be undertaken unless there is some reasonable expectation that there exists a market demand sufficiently large to justify that expenditure. In a technologically sophisticated capitalist society, with a range of versatile technological skills at the disposal of the capitalist decisionmaker, it would be sheer dereliction of responsibility were he or she *not* to consider the alternative courses of action available in terms of market size. At the same time, however, the range of actions which is available and their respective costs are being continually altered by the course of technical progress; the costs of alternative actions are always changing. This problem is exacerbated by the open-ended interview method used in these studies, in which business men are asked to reconstruct the decisions made in successful innovation processes. It seems obvious that no entrepreneur is going to admit to having gambled blindly on a technological potential alone, giving no thought at all to the profitability of its development. Nor is it realistic to expect an entrepreneur to plunge blindly ahead in such a fashion. Yet this in effect is the response necessary to demonstrate the primacy of "technology-push" in such a study. No wonder "technology-push" appears relatively unimportant!

In order to establish the proposition that market demand forces "called forth" an innovation, a shift in the demand curve must be shown to have occured (fig. 1). This is not to be confused, of course, with a movement along the demand curve (fig. 2).

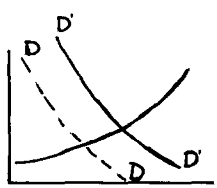

Fig. 1 DD to D'D'.

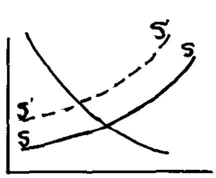

Fig. 2 S'S' to SS.

Distinguishing empirically between these types of parametric shifts raises an identification problem. Is an innovation introduced because the demand for a product has *increased* (i.e., the demand curve has shifted outward) or because technological improvements (or other sources of cost reduction). now make it possible to sell the product at a lower price (i.e., the downward shift in the supply curve leads to an intersection with the demand curve at a lower price than before)? The first case is the one required to support the "demand-pull' hypothesis. However, the information elicited from interviews with businessmen, given the nature and structure of the questions addressed to them, makes it virtually impossible to distinguish the demand-pull situation from that of technology-push. At the very least, as we have demonstrated, numerous instances of changes in production costs or requirements have been classified under "demand-pull."

When we ask why a particular innovation came at a particular point in time, it is never enough to say that it was "market demand." The question is why innovation did not come years earlier or later. The answer to such a question therefore has to deal with *changes* in demand- or supply-conditions. It is not sufficient to say that demand conditions "stimulated" or "triggered" an event; rather one must demonstrate changes in demand conditions. To establish the primacy of demand-side factors one has to show that demand conditions changed in ways more significant or decisive than changes in supply conditions – e.g., in cost. None of these studies deals with this identification problem.

The demand-pull approach reflects an insufficient appreciation for the innumerable ways in which changes, sometimes very small changes in production technology, are continually altering the potential costs of different lines of activity. It is these almost invisible, cumulative improvements in underlying technology, or the perception that it is possible to attain such improvements, or the realization that a cost-reducing technique in use in industry A is applicable (with perhaps minor modifications) in industries B, C and D, which play a critical and neglected role in accounting for the timing of innovative activity. The existence of an adequate demand for the eventual product is, of course, an essential – a necessary – condition. But, we suggest, the "demand-pull" approach simply ignores, or denies, the operation of a complex and diverse set of supply side mechanisms which are continually altering the structure of production costs (as well as introducing entirely new products) and which are therefore fundamental to the explanation of the timing of the innovation process.

At a more general level, the conceptual underpinnings of the "demand-pull" case are perhaps even more fundamentally suspect. Rather than viewing either the existence of a market demand or the existence of a technological opportunity as each representing a sufficient condition for innovation to occur, one should consider them each as necessary, but not sufficient, for innovation to result; both must exist simultaneously. There is no good *a priori* reason in theory why "market demand" factors should be dominant in motivating innovative activity. If we assume the world to be populated by firms attempting to maximize profits, *any* environmental shift presenting an opportunity for technical change yielding a net profit will be taken, regardless of whether it derives from a shift in market demand, a change in the conditions of supply, or a promising technical breakthourgh. A whole range of stimuli are important in the innovation process, not simply market demand. Moreover, any careful study of the history of an innovation is likely to reveal a characteristically iterative process, in which *both* demand and supply forces are responded to. Thus, successful innovations typically undergo extensive modification in the development process in response to the perception of the requirements of the eventual users, on the one hand, and, on the other, in response to the requirements of the producer who is interested in producing the product at the lowest possible cost. Innovations which are not highly sensitive to *both* sets of forces are most unlikely to achieve the status of commercial success.[16]

The limited usefulness of the "demand-pull' conceptualization is demonstrated in attempts to apply the conclusions thence derived at a level of aggregation above that of the individual firm; there is no clear mechanism by means of which to move from the micro to the macro level of analysis with such a model. Thus, in comparing the innovative performance of nations, Pavitt notes that

> ... the empirical evidence suggests that there is in fact a weak relationship between the size and sophistication of national markets, and performance in technological innovation... much higher correlations with national innovative performance exist for 'supply' rather than 'demand' factors, such as the number of large firms, the level of industrial R and D, and capabilities in fundamental research. ([27], p. 53)

[16] This is shown in the SAPPHO [34] and FIP [43] studies on the conditions responsible for commercial success in innovation, as well as in [48].

This applies with equal force in the comparison of the innovative performance of industries within a national unit; whatever evidence exists (and little of an unambiguous variety may be said to exist) relating the rate of innovation to attributes of various industries in a cross-sectional comparison without exception deals with "supply side" variables, including such factors as producer concentration and "technological opportunity".[17] The work of Schmookler concerning the cross-sectional comparison of industries uses patents as its dependent variable, and thus should be seen primarily as explaining the allocation of inventive effort, since the set of patented inventions bears a tenuous relation, as Schmookler recognized, to the much smaller set of commercially successful innovations. Not only do most patents never reach the stage of commercial exploitation, but many commercially successful innovations are unpatented. Moreover, it seems reasonable to ask of a theory of innovation that it allow one to compare the performance of industries and nations; this certainly is of importance for policy purposes. The "demand-pull" theories of innovation cannot be said to be useful theories on this score. These theories in no way provide a satisfactory account for one of the most distinctive features of industrial societies: the wide variations in the performance of individual industries with respect to observed rates of technological innovation and productivity growth.

In addition to providing very little useful information on the comparative performance of national and industrial aggregates in innovation, the "demand-pull" approach to innovation reveals little about the specific timing and direction of innovative *output*. Even if one grants, as we do not, a dominant role for demand in the innovation process as asserted in these empirical studies, their findings relate to the stimuli for innovation, the influences upon the allocation of R & D inputs, not the rate and direction of outputs, which are the variables which one wants to explain. Many of the findings of the studies also refer to attributes, or measures of the success, of innovations, rather than characteristics distinguishing success from failure in innovation. Clearly, an "understanding of user needs," or the "satisfaction of an anticipated demand," are really criteria which define successful innovations. They hardly qualify as independent explanatory variables. Many of these empirical studies, particularly those which analyze the process from the viewpoint of a single firm, adopt a "black box" explanation of the innovation process: inputs in, innovations out.

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[17] See [38] for a good empirical cross-national analysis.

A recent article, "Problems in the Economist's Conceptualization of Technological Innovation" ([32], ch. 4), criticized the notion of a smooth, convex, well-defined isoquant in most microeconomic theorizing in which the structure of relative factor prices yields a determinate solution to the choice of technique problem under all circumstances. In many of these studies of innovation, the implicit idea of a well defined innovation possibility frontier, based upon scientific knowledge, which underpins the black-box approach, is open to serious criticism on similar grounds: the search for the basic knowledge for solutions to problems is not costless, nor does the knowledge base merely fulfill a passive "blueprint" role in the innovation process.

The exclusive focus upon the outcomes of a complex process (in this case, innovations), which has long been the *modus operandi* of the economist, can be justified only in an environment of certainty and equilibrium, as Herbert Simon pointed out:

> ... The equilibrium behavior of a perfectly adapting organism depends only on its goal and its environment; it is otherwise completely independent of the internal properties of the organism... but when the complexity and instability of his environment becomes a central feature of the choices that economic man faces... the theory must describe him as something more than a featureless adaptive organism: it must incorporate at least some description of the processes and mechanisms through which the adaption takes place. ([41], p. 3)

The notion that the market transmits clear and readily-recognized signals for innovations is important to the validity of the "black box" approach to the analysis of innovation. Yet Nelson has noted that the existence of such a mechanism is a rather shaky assumption:

> The assumption of a well-perceived demand curve for product or supply curve for input is plausible only if one can describe mechanisms whereby these curves in fact get well perceived. This would seem to imply considerable experience on the part of the firms in the industry in the relevant environment of demand and supply conditions. This clearly cannot be assumed in an environment of rapid change in either demand or supply conditions. In particular, it seems completely implausible in considering the demand for a major innovation. ([25], p. 46)

Indeed, the pervasiveness of uncertainty in the innovation process is ignored by most of the empirical studies. This is particularly true of the studies which have as their unit of analysis some group of selected innovations, and which attempt to reconstruct the history of such innovations: HINDSIGHT, TRACES, and the Battelle study are prominent examples. The attempt to decompose neatly the complex, stochastic, and uncertain process which is that leading to innovations into a set of events which can simply be cumulated to yield an innovation, is as gross an oversimplification as is the "black box" approach of the surveys of business firms. To attempt such a reconstruction, and further to attempt to ascribe relative importance to the various categories of research events (as in HINDSIGHT), seems fallacious.

The innovation process surely comprises an area of economic behavior in which uncertainty and complexity are absolutely central characteristics of the environment; empirical approaches to the problem must therefore take far greater cognizance of the processes which underlie the output of innovations. Rather than focussing exclusively upon innovational outputs at widely separated times, a more fruitful approach might be that of tracing the growth and evolution of a given organizational form involved in the research and innovation processes, in an effort to provide a somewhat deeper analysis of the evolution of the information flows and processes which are responsible for success (or failure) in the production of innovations over a period of time; changing the unit of analysis in this manner might yield a richer set of conclusions and studies than is currently the case.

Some of the literature in the field of technological change produced by economists represents an effort to get at structural aspects of the innovation process, whether through the construction of innovation production functions or, more narrowly, attempting to relate certain structural parameters of firms or industries to innovative performance or research intensity. However, this body of literature, for all its merits in explicitly examining the structural and institutional aspects of the process, is largely ahistorical. Empirical studies which pursue the historical background are confined to dealing with a particular innovation. Confining the unit of analysis to the single firm in these empirical studies also creates problems, due to the lack of attention devoted to interfirm relationships, which are often central in the understanding of technical change. This is clearly illustrated in an article by Abernathy and Townsend [1] in which the unit of analysis is rendered more conformable with the underlying technology, yielding a substantially different set of conclusions dealing with the same data which Myers and Marquis considered. Just as much of the new work in industrial organization frequently concerns product lines, rather than the often – and increasingly – artificial boundaries of the firm, so should empirical analyses of technologies remove the blinders imposed by concentration upon the single firm in isolation. The present paper will have served a useful purpose, if only of a preliminary, "deck-clearing" nature, if it has persuaded the reader that the now widely-accepted bit of conventional wisdom concerning the primacy of "demand-pull" forces in the innovation process is lacking in any persuasive empirical support.

SOME POLICY IMPLICATIONS

What implications follow from the discussion above for governmental science and technology policies? The fundamental conclusion is that the current stock of scientific and technical knowledge is *not* omnicompetent, and that an active role for government in affecting the rate and direction of innovation is necessary, one going beyond the prescription below:

> The emphasis of both direct and indirect government intervention in the economy should be to transform the market in ways which will encourage industry to innovate products of better quality and greater social utility... it should create the incentives and disincentives which will encourage industries to be more innovative in the use of their R and D resources. ([12], p 39

While we agree with Gilpin's statement as far as it goes, it does not go nearly far enough. The government ought indeed to take whatever steps it can to improve the functioning of the private market and the complex incentive system which is mediated through market forces. But such measures, although eminently desirable, are not nearly sufficient. For the production of new knowledge which underlies and shapes the innovative process is, itself, very inadequately served by market forces and the incentives of the market place. The need for a more positive public policy is well-recognized both by numerous scholarly studies which have documented the discrepancy between high social returns and low (or even negative) private returns with respect to investment in knowledge production, and the diverse and elaborate systems of public support of knowledge-producing activities which have emerged in all advanced industrial societies. Attempting to deal with such problem has, for example, produced quite different organizational arrangements in America with respect to such diverse sectors as medicine, aircraft, atomic energy and agriculture. There are, in addition, many forms of knowledge which are urgently required for successful social policy, which will not be produced through any plausible system of private market incentives. Further thought concerning the most efficient ways of organizing the R & D process is urgently needed.

The point is that in certain areas, such as alternative energy or antipollution technologies, industries may simply lack sufficient R & D resources or the necessary market-generated incentives. In many industries and areas of substantial social need, we simply do not have the basic knowledge of scientific and technical phenomena to proceed intelligently; our limited understanding of such complex ecosystems as San Francisco Bay, for example, or of the effects upon human health of long-term exposure to certain industrial wastes, greatly hampers the development of optimal antipollutant technologies and regulations. It is important to understand that the record of postwar American technical dynamism is a direct outgrowth of scientific and technical research in a very few areas (such as electronics), often funded and justified by defense requirements. This knowledge is clearly transferable in certain cases – semiconductors are an obvious example – to the civilian sector, but it is limited in its range of applicability. Integrated circuits will not immediately eradicate urban blight.

The semiconductor electronics industry provides a useful example of an extremely progressive industry, which has been characterized by sensitivity to demand factors, but which has also been fundamentally governed by the exploitation of a new body of scientific and technical knowledge.[18] The industry represents perhaps the most outstanding "success story," in terms of government policy to stimulate technical progressiveness, and growth in output and employment, in the postwar period in the United States. This revolution in electronics which has stretched over the last three decades does not represent a response to sudden shifts or increases in market demand, but rather reflects the increasingly wide exploitation of new technical capabilities, based upon advances in solid-state physics and production technologies. Clearly, the record of innovation in the industry has been one of sensitivity to the desires of customers (it is hard to see how matters could have been otherwise), particularly military customers. Yet, the case simply cannot be made that this demand for miniaturized solid-state components and logic functions was one which alone or primarily brought the industry into being. It is the

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[18] Both [13] and [45], the two best references on the semiconductor industry, emphasize this point.

exploitation of the radically new properties and capacities of semiconductors and integrated circuits which has been a mainspring of the industry's growth. Innovative effort has been directed at the solution of problems of application and production of this technology. The fundamental "focusing devices" have been internal to the development of the technology, rather than being explicable by reference to exogenous demand forces. Process innovations, grounded in theoretical and technical developments, have been fundamental in the history of product innovation in the industry.

An important role thus exists for government funding of certain kinds of scientific and technical research in a broader range of non-defense areas, perhaps including some limited involvement in the construction of pilot plants, similar to the DoD policy of the early 1950's concerning transistors. Attempting to revolutionize the technological underpinnings of certain sectors through the resort to a "big push" approach, however, is likely to fail – cognizance must be taken of the fact that the basic knowledge may be lacking, as well as the complexity of market demand and the interface between successful government and private development efforts. Of course, advocates of the "demand-pull" approach are absolutely right insofar as they insist that money poured into schemes for which no demand exists is likely to be money wasted. But, as we have seen, they claim far more than that for their position.

In addition to nourishing the supply side in a broader range of areas, intelligent policies must be directed at institutional aspects of the innovation process, working to encourage the interaction of users and producers, as well as the iterative interactions between more basic and applied research enterprises. We do not yet understand the characteristics of the innovation process sufficiently well, nor do we possess the necessary knowledge base in certain areas of substantial social utility. Useful policies would be those directed at the provision of information, from basic research institutions in the noncommercial sector to private firms and laboratories, as well as from users to producers concerning desired products and characteristics.

More generally, policies directed toward increasing both the frequency and the intimacy of interactions among these separate participant groups may prove to be particularly rewarding. This involves not only expanding the network on which information may flow among these groups but, additionally, measures which will increase the incentive to participate in such interactions.

An additional point of importance focuses upon the limited policy relevance of the demand pull position, which was mentioned above. Based as it is upon the hypothesized motivations and actions of individual firms, policies aimed at industries and sectors do not follow easily from the "demand-pull" conceptualization of technical innovation. A recent paper by Gibbons and Gummett discussed the efforts of the British government to develop structures to provide "demand-pulls" for the numerous research laboratories of the Department of Industry. The authors emphasize that it is still too early to assess the success of the new "Research Requirements Boards," but they note that the "... problem of trying to aggregate individual strategies into sector strategies and, hence, sector needs has, to our knowledge, received very little attention so far... one is left in the dark about how these needs are to be identified" ([10], pp. 27–28). Such a set of difficulties inevitably will plague efforts to "call forth" commercially successful innovations from private or public research institutions.

It is important to point out in conclusion that the above policy prescriptions are directed at the encouragement of innovation, not the diffusion of innovations. This second problem is one of equal importance to the national policymaker concerned with productivity growth and related problems. Encouragement of the diffusion of innovations, however, seems to be an area in which one can indeed rely upon the more conventional market incentives designed to induce a demand-pull for a proven innovation. Certainly, the policies proposed above which are directed at the improvement of communications between users and producers would also be useful in the encouragement of the diffusion of innovations. But, while one may rely upon the ordinary forces of the market place to bring about a rapid diffusion of an existing innovation with good profit prospects, one can hardly rely completely upon such forces for the initial generation of such innovations.

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