INDUSTRIAL INNOVATION AND GOVERNMENTAL POLICY: A REVIEW AND PROPOSAL BASED ON OBSERVATIONS OF THE U.S. ELECTRONICS SECTOR

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ABSTRACT

The U.S. electronics sector has been particularly successful at technological innovation since the 1940s. This paper addresses governmental policies that influence the process of technological innovation, drawing on aspects of the history of the electronics sector. Three topics receive particular attention—(1) uncertainties, ideas, and imperfect appropriability, (2) returns to R&D and associated investments, and (3) competition and selection environments. As a foundation for this discussion, several conceptual frameworks are briefly described and some classifications for innovation are explored, i.e., by importance (basic/improvement), by locus of change (process/product), by area of application (peaceful/dangerous), by locus of choice (private/public), and by value (worthwhile/not worthwhile). The discussion is underscored by the observation that better links between conceptual understanding and policy formulation are needed in order to derive practical insights into useful actions. One specific policy recommendation is tendered: an income tax credit on earnings of all employees (including salaried staff and managers) of R&D intensive firms. Such a policy would be appropriate from the standpoint of the topics outlined above (i.e., uncertainties, returns to R&D, and competition); the policy would also delegate responsibility for effective use of the subsidy to the employees and firms affected, and would directly acknowledge and reward the contributions of individuals—whether in R&D, production, marketing, or support areas—to the innovative capabilities of their firms and the society at large.

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I. PERSPECTIVES ON THE "REAL WORLD"[1]

When economists leave their theoretical models aside, they often refer to circumstances in the "real world." This reality is, of course, much more complex than the economists' theoretical formulations, but it is precisely the simplifying assumptions that allow the theorist to analyze fundamental influences conceptually and to verify them empirically.

Like theory development, policy formulation and implementation also depend on abstractions from the "real world." In April 1978 President Carter initiated a "Domestic Policy Review of Industrial Innovation" for the United States. The Secretary of Commerce was charged with leading the review to answer the question, "What actions should the Federal Government take to encourage technological innovation?" Suggestions were sought from business, labor, and consumer groups as well as from "experts." The observations, analyses, and opinions rendered during this process had to be interpreted in the light of broader economic and political considerations before the President's "Industrial Innovation Initiatives" were formulated and promulgated (Carter 1979).

The legislative branch has also been active. Staffers have sought information and drafted position papers, hearings have been held,[2] and specific pieces of legislation have been formulated.

Meanwhile the "real world" continues to evolve: new products are announced, new companies are formed, and some of the existing companies "disappear" through merger or bankruptcy. The "real world" is changing and new problems are arising. The policy formulation

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[1]A preliminary version of this paper was prepared for presentation at the International Institute for Applied Systems Analysis' Workshop on Innovation Policy and Firm Strategy, 4-6 December 1979, Schloss Laxenburg, Austria, under sponsorship of The Rand Corporation, Santa Monica, California, as part of its program of public service. Support for this work is gratefully acknowledged, but the views expressed are the author's own, and are not necessarily shared by Rand or its research sponsors.

[2]See Industrial Technology (1978), which provides the record of a hearing on governmental policy and innovation in the semiconductor and computer industries, together with a summary of several previous hearings on industrial technology; see also Gilpin (1975).

process resulting directly from the Domestic Policy Review will continue for several years, during which time legislative and other action will be taken. Policy action will often take several more years to be fully implemented. Some implementation steps will be undertaken by individuals with limited understanding of the "subtle and intricate process" (Carter 1979, p.5) that they will be charged with influencing. Thus the policy process can produce errors in governmental action affecting technological innovation as easily as the simplifying assumptions of the theorist can produce errors of insight about the innovation process.

In short, conceptual formulations attempt to interpret reality and policy initiatives attempt to influence reality. Like the two fists of a boxer, it would be highly desirable if the two approaches were coordinated and directed at identifying and ameliorating or removing real problems, each approach sensitive to the many subtleties and limitations of the other. Even then there would be value issues to resolve—e.g., the choice of "targets" for policy actions. But too often theoretical models and policy initiatives are developed independently of one another, are often uncoordinated—more analogous to the claws of a lobster than the fists of a boxer—and can produce unforeseen interference as well as progress.

In this paper I will both briefly sketch a few of the competing conceptual formulations for understanding technological innovation at the firm and industry level of aggregation, and discuss some of the policy actions that have been considered (or taken) in the past—in the context of the U.S. electronics sector. In the course of these observations, I will comment on the need for further research and policy initiatives.

Although the principal objective of this paper is to foster discussion, a specific policy recommendation is tendered. To simulate technological innovation while delegating to the firm the responsibility of choice among options, I have suggested a personal income tax credit on earnings of all employees and salaried staff and managers of R&D intensive firms. This would become, to some extent, an indirect subsidy to the firms—one that could be used for a range of options, such as further R&D, new hiring, capital investment, etc. This policy would be relatively more favorable to smaller and more labor-intensive firms; it would also avoid some of the inherent biases favoring high income tax brackets as found in many capital gains tax proposals. The fiscal impact of the policy would have to be coordinated with broader fiscal policy objectives, and perhaps enacted in conjunction with encouragement of new investment and/or greater venture capital availability. One of the main objectives of such an income tax credit would be to directly acknowledge and reward the contribution of individuals—whether in R&D, production, marketing, or support areas—to the innovative capabilities and economic vitality of their firms and the society at large.

II. CONCEPTUAL APPROACHES TO TECHNOLOGICAL INNOVATION

The term "innovation" is widely used today to describe aspects of economic growth and development; innovation is also identified as an objective of a variety of national policy instruments. Simon Kuznets (1971, especially Ch. 7) has theorized that economic growth and development can be viewed in very long time streams. He has identified what he has called "economic epochs" extending over a period of more than a century; in his view each epoch is characterized by an "epochal innovation," something so fundamental to the societies of the time that it helps to generate a whole stream of activities. He has labeled one such epoch "mercantile capitalism," extending between the end of the fifteenth century and the second half of the eighteenth century. A major influence during this period was radically changing geographic perceptions of the world, centering around the discovery of the "new world." Overseas trade was an important element contributing to the growth of individual nations during this period. Our "modern" economic growth began in the succeeding epoch, during the late eighteenth century. According to Kuznets, this period has been characterized by extended application of science to problems of economic production.

Such views of the past may be helpful in drawing lessons from history, but it would be very difficult for contemporary man to identify the commencement of a new economic epoch of this sort. Some conclusions have been drawn about the importance of computers, or the "information society." But even with the major progress that has been made in this century in quantitative measurement of economic growth, methodologies for measuring changes in the quality of goods and services available within and between nations are either nonexistent or extremely crude.

The Innovation Process

If we view "technological innovation" as the introduction of a new or significantly improved product or process into the economy through the application of modern technology, then quality change and cost constitute the essence of such innovation. In recent decades, governments and firms have expended considerable energy and resources in attempts to organize the innovation process efficiently and to direct it toward useful[8] results.

Feedback from one stage of the research and development (R&D) process can help in formulation or reformulation at other stages; learning must take place so that an innovative concept can be confirmed to be both technically feasible and desired by the user. The qualitative nature of purely process innovations permits them to be measured relatively easily and quantitatively—in terms of cost reductions in the delivery of an identical end product. In contrast, the qualitative nature of product innovations is much more complicated, especially because the original objectives of the innovation may turn out to be secondary to other applications that are discovered after the innovation has become more widely diffused into an economy. For example, the demanding requirements for reliability and security of real-time applications of computers in the financial sector were hardly anticipated when the first computers were being introduced.

Serendipity plays an important role in the historical development of a branch of technology and its applications. The lines of descent of today's technological innovations can be studied, but it is much more difficult to anticipate the future directions of current trends. The antecedents of the U.S. electronics sector can be traced back to the first prototype light bulb burned by Thomas Edison a hundred years ago. The earliest antecedents of the high volume production of much of today's electronics circuitry should include Eli Whitney's invention of rifles with interchangeable parts, as well as Henry Ford's mass production techniques.

[8] "Useful" here refers to the distinction between innovations which yield quality changes that are "worth" what they cost and those which are not.

Opportunities to commercialize the results of these innovations were different; in the Whitney and Ford examples, a well-defined market opportunity existed. The needs of the ultimate user in terms of both product quality and price were critical to the success of all the innovations.

It is difficult to summarize succinctly the meaning of the phrase "anticipating the needs of the final user."[4] In part this stems from the variety of potential final users for the vast array of goods and services available in an economy like that of the United States. Also, most of the goods and services are amenable to some form of technological innovation over time, so that either the characteristics of the product sought by the final user or the cost of production is susceptible to change. In Figure 1 a categorization scheme is suggested for distinguishing between choices of final goods and services by either private or public decisionmakers, as well as for considering the applicability of these choices to two broad categories of final goods and services— identified as "peaceful" or "dangerous." These distinctions are by no means clear-cut; the categories "peaceful" and "dangerous" are descriptions of the extremes of a continuum of goods and services (hereafter referred to as "products") rather than mutually exclusive categories. Research and development can lead to technological innovations in either of these categories. Moreover, the earlier the stage of the R&D process (e.g., basic research), the less identifiable is the work with either of the extremes of this continuum (or any point in between). If we distinguish between technological innovations that are "basic"[5] and those that constitute "improvements," we should recognize that basic innovations can be motivated by end-uses at any point along the spectrum of final products. Innovations that led to the emergence of the English cotton textile industry in the late eighteenth century and the development of atomic energy in the mid-twentieth century illustrate this point.

"Improvement" innovations can have two different objectives; they can enhance products subsequent to the original application of a basic innovation (e.g., improvements in spinning and weaving machinery or in nuclear weapons design), or they can permit the application of a basic innovation for new-end uses, i.e., a movement on the continuum between peaceful and dangerous products. The directions of such innovations are motivated by the "needs" that are perceived to be worth satisfying.

Thus, consideration of decisionmaking about uses of the final products reveals influences on technological innovation from sources other than technology. For final products that are not "dangerous" and for which private choices are most relevant, market forces have been demonstrated, both theoretically and empirically, to efficiently allocate scarce resources and to provide signals about the need for further technological innovation. The limited acceptance of the initial strains of high-yield rice produced in what has come to be called the "green revolution" occurred because the reduction in product quality (e.g., tastiness and texture) had unanticipated consequences for prices. "Improvement" innovations were needed to enhance the quality of the new strains, to make them more competitive with available alternatives. Such innovative activities can occur without deliberate public sector intervention.[6] In contrast, public choice is widely recognized as the relevant perspective for products relating to a nation's military capability, and market forces would provide inadequate guidance for technological innovation. Under such circumstances, reliance is placed on bureaucratic and political decisions.

It is important to consider these distinctions explicitly, for national security requirements, as perceived by national interests, govern a great deal of publicly supported R&D.[7] All countries rely to some degree on bureaucratic and political decisionmaking in assessing the "needs"

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[4]Also, the "needs" a firm deems worth satisfying may be different from the "needs" viewed as important by society at large.

[5]"Basic" innovations imply the opening up of a whole new field of product applications, or permit efficiency improvements through the development of a new technology.

[6]The crucial ingredient, as Nancy Nimitz emphasizes, is the existence of cost-conscious and discriminating buyers.

[7]These "national interests" may be subject to a broad range of interpretation at a particular point in time, for instance by leaders as different as Winston Churchill, Joseph Stalin, Franklin Delano Roosevelt, and Adolf Hitler.

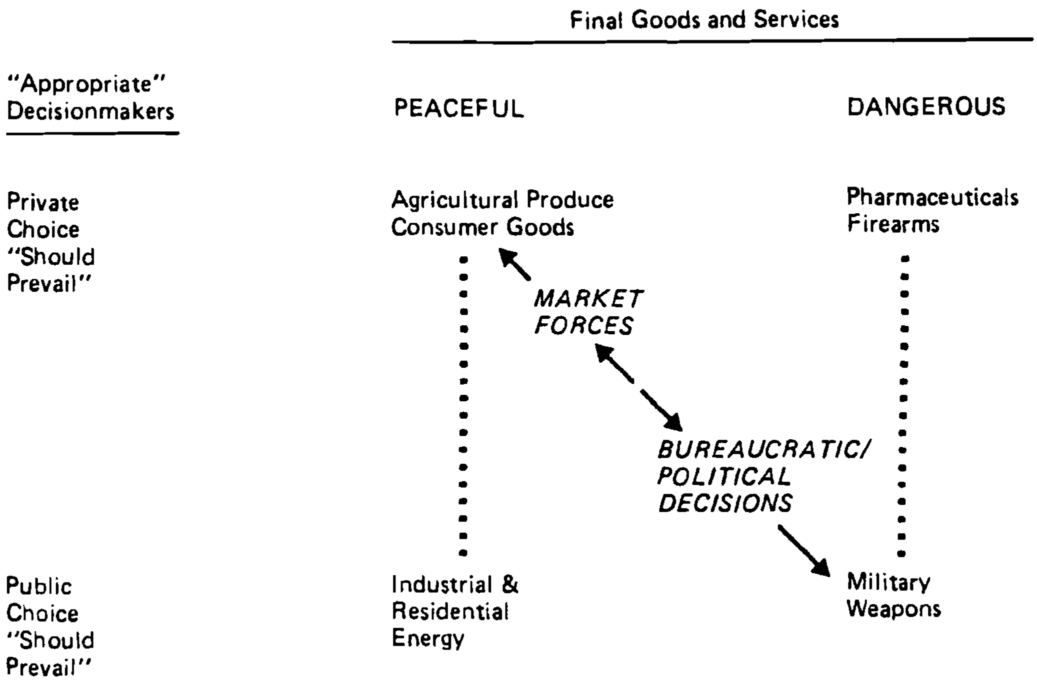

Figure 1. Microanalytic view of final goods and services, and private or public choice

that determine allocation of publicly and privately supported R&D.

This discussion of the roles of market forces and bureaucratic/political decisions in clarifying the needs of the ultimate user—to whom successful technological innovation is directed—is applicable (to a greater or lesser extent) across the whole continuum of final products. For example, there are recognized and legitimate roles for government regulation of pharmaceuticals in the health-care delivery field in the United States. There is also an expanding government role in determining appropriate rates of reimbursement for medical services, as well as activities by the courts in determining responsibility and damages for malpractice. It is striking that such public sector activities exist in an environment in which the medical profession has traditionally been relied upon to seek improvements in modes of medical intervention, in which the hospital sector has sought to attract physicians to its staff through non-price competition (e.g., investments in the latest medical technologies), and in which the recipients of medical services are widely regarded as having incomplete information for choosing among medical services and few incentives for being "cost conscious" in such choices. Satisfaction of the "needs of the ultimate user" through further technological innovation in medical equipment and instrumentation involves responding to a very complex set of "market" incentives; in such circumstances, public policy initiatives can have quite unanticipated effects (Rettig and Harman 1979).

Economic Concepts

The activities of industrial enterprises (firms) undertaking technological innovation should be analyzed within a conceptual framework that captures the personal motivations of the participants, as well as more structured decision processes regarding product objectives. This framework should take into consideration both the context of market forces and the non-market environment. Despite a great deal of economic research on this topic, no concensus has been reached regarding such a conceptual framework. Thus, it seems desirable to use an eclectic approach as a guide to policy formulation.

Neoclassical theory has been receiving increasingly critical reviews in recent years. Still, it retains the advantage of being the most parsimonious description of the essential elements of a firm's economic motivations. Neoclassical theory ignores, however, the intrinsic uncertainties of the R&D process, treating them at best as an a priori known distribution of risky outcomes.[8]

Two other approaches to understanding firm behavior appear particularly intriguing. Nelson and Winter (1977) have argued for an evolutionary theory; it includes modeling of the intrinsic uncertainties of the innovative process with the aid of a set of conditional probabilistic outcomes of varous R&D strategies. Nelson and Winter have also suggested that it may be important to recognize the role of institutional structures, in various economic sectors, in determining innovative outcomes. There may be a variety of "selection environments" that capture the competitive aspects of firm behavior and the needs of the ultimate user. These "selection environments" incorporate three elements: the determination of the "worth" (e.g., profit) of innovation activities by firms, the ways in which consumer and regulatory demands shape profitability, and the investment and imitation processes that are involved.

Nelson and Winter consider both market and nonmarket "selection environments." The principle distinction they propose is that in nonmarket sectors the interests of "firms" and "customers" are not as sharply defined as in the market sectors. They suggest that "natural trajectories" of technologies occur in which obvious weak spots in product designs or targets for improvement can be identified. Such natural trajectories can lead to rapid advancements in some economic sectors, while other sectors, lacking such natural trajectories, progress more slowly. The development of electronic components from vacuum tubes to very large scale integrated (VLSI) circuitry seems to provide an example of a natural trajectory. The widely used S-shaped curve of technological advancement—i.e., initial rapid advancement in terms of quality enhancement of an end-product's principal dimensions, and then a slowing—can be understood in terms of such trajectories and their underlying scientific and technological base.

In contrast, Klein suggests an explanation based on a dynamic theory:

> The principal reason why technologies come to be defined very narrowly and why the rate of progress eventually slows down is not because of a shortage of ideas, but rather because of a shortage of hidden foot feedback. Hidden foot feedback is the feedback a firm obtains from its rivals; and it is measured in terms of changes in market share... Inasmuch as what is a technological risk to one firm in an industry, is a competitive risk to another, the more technological risk-taking that is undertaken in developing products with nontrivial differences, the greater will be the changes in market shares.... Almost inevitably, the larger the advances that are sought, the wider will be the differences between more and less successful R&D projects, and the larger will be the change in market shares [Klein 1979, pp.7-8].

Thus, Klein argues that intensive technological innovation and rapid rates of technological progress by firms are derived from the threat of a potentially successful rival. He further argues that the successful firm—one that grows and as a result becomes more bureaucratic—becomes susceptible to narrowing the range of investigation for resolving future uncertainties, and hence for coming up with further innovations. Klein argues that the rate of technological innovation

[8] The author has used this approach in the past, with its many simplifying assumptions; see Harman 1971, Ch. 8. See also the Appendix, to which the policy discussion below refers.

for an individual firm may slow because of the tendency of such internal bureaucracy to establish routines and to preserve the status quo. The principal factor that determines whether or not the industry remains "dynamic" (i.e., continues with rapid introduction of new process or product innovations) is the ability of new firms to enter the industry.

Finally, technological innovation in general has also been stimulated in important ways by the demands of a diverse and international marketplace.[9] The standard conception of international trade explains trade patterns according to a nation's comparative advantage for efficient production, based on the relative abundance of its resources, labor, and capital. An important extension of this theory, to the sphere of newly developed products, interprets international trade as being based on technology itself. The theory has also been extended to include the concept of a product life cycle, in which the ability to produce certain products by firms in various countries changes over time.[10]

In early phases, few firms are innovators, and have the required production know-how. As technology diffuses and imitation occurs, trade patterns are influenced more strongly by the traditional factors that determine comparative advantage. For example, standard electronic components that involve labor-intensive production will be cheaper for U.S. producers and final consumers if they are imported from countries where labor is relatively cheaper than in the United States.

A firm can maintain its comparative advantage by continuing to evolve its product line in advance of its competitors (see Harman 1971, Ch. 3). This can occur, of course, only as long as a scientific and technological base exists to support such technological innovation and as long as the means of at least temporarily capturing the economic gains of the innovative activities are sustained. In other words, products will have periods of rapid growth and international marketing, followed by periods of consolidation. "Consolidation" may not mean a slowing of the potential for further technological advances; but the new products that could be developed may not be sufficiently valued by users to merit the price that would have to be charged for them in the national or international marketplace.

Thus, technologically determined trade patterns are intrinsically temporary, though they may last for a long time. The U.S. advantage in computers and semiconductors has been fostered by a continuing stream of advances in technology. At the upper end of the computer lines, this advantage is still unchallenged internationally—no less than four U.S. firms compete for customers. Some recent developments, such as the network-oriented computer, have been made possible in part by the new capabilities of the semiconductor industry. Such developments suggest that the American computer industry is continuing to be innovative. Participation in international markets not only affects the U.S balance of payments, but also provides opportunities for access to a wide spectrum of new ideas, so necessary to further product developments.

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[9] This is true for semiconductors and computers in particular.

[10] See for example, Vernon 1967 and also Hufbauer 1970.

III. SOME OBSERVATIONS ON POLICY LEVERAGE[11]

Uncertainties, Ideas, and Imperfect Appropriability

A fitting place to begin the discussion of policy leverage on technological innovation is with the motivations of the individual. A wide spectrum of individuals is needed for successful technological innovation (or, alternatively, individuals with a wide spectrum of capabilities). Not only an "inventor" and "developer," is needed, but also a "product champion" who makes the case for backing a particular concept throughout its development process, a "gatekeeper" who helps with the flow of information within a large organization and between the organization and the outside world, a "production specialist" who keeps the concern for production efficiency prominent during the development process as well as during production, "salesmen" who distribute the end products and provide the organization with feedback regarding the unmet needs of various classes of users, and an "entrepreneur." (See, for example, Zaltman et al. 1973.) A president of one of the U.S. semiconductor firms describes the importance of these individuals as follows:

> For us to maintain technological leadership in a competitive world we must stimulate the total society to find its strength in its own members. Novelty comes from a self-confident personality. This entrepreneur will create innovations for the pure zest of achievement through the incentive of the well-being of himself, his loved ones and his neighbors.

In essence, the process of successful technological innovation ultimately depends on one or more individuals coming up with good ideas. The exploration of good ideas—the difficult process of resolving uncertainties to achieve a successful new product or process—cannot be measured simply in terms of dollars expended. Some concepts for the new design of a piece of computer hardware may rely on readily available electronic components or technologies. In fact, the Amdahl line of computers used components for memories that were available "off-the-shelf" from more than one source. Novelty in the design came from efficiently packing the components, while maintaining competitive sources of supply.[12]

Direct Support of R&D

Government policies can affect the development of new ideas in a number of ways.[13] First of all, financial backing for basic research activities has been considered a legitimate role of government both theoretically and in practice. In recent times, privately funded basic research has been significantly curtailed (see Nason et al. 1978; Industrial Technology 1978,

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[11] This section draws upon the experience of the computer and semiconductor industries. Principal sources used include Industrial Innovation (1978), Braun and MacDonald (1978), Phister (1974), Tilton (1971), and Harman (1971). The quotes from executives included in this section were taken from correspondence following a hearing before the U.S. Senate Committee on Commerce, Science and Transportation (Industrial Technology 1978). In the preparation of earlier remarks (Harman 1978), on which this section is based, the author benefited greatly from exchanges of ideas with R. Anderson, A. Alexander, W. Baer, C. Eads, F.M. Fisher, D. Jaffee, E. Mansfield, R. Perry, R. Rettig, E. Thomas, J. Utterback, and W. Ware. The author is also indebted to Rand Graduate Institute students—and particularly to J.L. Burns, B.W. Don, L.B. Embry, and W.L. Schwabe—for stimulating discussions of some of these issues.

[12] For further description of the design of this memory and the entire Amdahl computer, see Harman et al. 1977, pp. 37-41.

[13] For the purposes of this discussion the very important role that government actions can play in the rapid and low cost dissemination of information is left aside. One of President Carter's nine areas of initatives includes such actions—for example, increased monitoring of information on foreign R&D activities (Carter 1979, pp.2-3).

p.33; and Carter 1979, p.4). In the context of augmenting basic research support, it seems important to try to develop a closer link between industry and the universities. In this connection the view of another President of a semiconductor firm is relevant:

> We believe that closer links are very desirable. Our endorsement is based on our participation in and observation of the excellent links between Stanford and local industry. We are also aware that this came about through a vision and interest of a few individuals and is not generally experienced by most universities and their industrial neighbors.
>
> An approach that might be considered is to revise the federal income tax laws to provide a tax credit for corporate funds that are given to universities for research. Since this would supplement and not replace government research grants, the amounts would have to be limited. Perhaps two or three percent of a company's in-house R&D budget would be an appropriate ceiling. On a $25 billion base, two percent would generate a maximum of $500 million, which would represent about a ten percent increase in university research funds.

Government funding at a later stage of R&D has also been important. After World War II the U.S. government promoted considerable activity in both the computer and semiconductor fields through its defense programs and later through its space program. More recently the Japanese government has used the direct subsidy route, with funding estimated to be on the order of $500 million or more. The British government also is investing in its semiconductor industry, on the order of 50 to 100 million pounds. The French government has several activities in progress which involve investments in the French semiconductor industry, and the Korean government is trying to establish a viable semiconductor industry committed to consumer goods applications (Corrigan 1978, pp.31-32). Thus, direct government support of R&D is a widespread mechanism for helping in the development of new ideas to sustain a country's technological innovations; the level of government resources committed to the support of technological innovation is one measure of the seriousness with which the government and the companies in a given country are pursuing new technologies. However, it is not necessarily a good measure of successful innovations.

Patent Policies

The patent system is, of course, designed to encourage the development of new ideas—"flashes of creative genius." This is clearly an area in which policy implementation can have important repercussions. Note, for instance, the difficulties that were caused by the extreme delay in the granting of a patent, as in the case of ENIAC computer (see Harman 1978, pp.6, 9; and Gilpin 1975). New challenges are presented by the need to protect such intangibles as computer programs.

Towards a New Tax Policy for Innovation

The many individuals who contribute to the creation and practical development of new ideas collectively form the "labor" component of neoclassical production functions. In the Appendix, a very simplified model of induced technological innovation is presented to illustrate that a firm's investment in enhancement of labor productivity is directly related to its total expenditure on labor and inversely proportional to the marginal cost of improving labor productivity. Fisher has observed that some labor skills may not receive the full "rents" due to them in the process of technological innovation.

> Even the case of special managerial skills need not result in rents being fully inputed to the factors of production with which they are properly associated. Particularly in large firms dealing with complicated and delicate technologies, it is perfectly possible for the added efficiency to accrue not to any small group of individuals but to the firm as a whole. If that is true, then while it would be possible for others to bid away any small group of individuals, managerial efficiencies would still rest in the organization, the whole being greater than the sum of its parts. In that circumstance there would still be unimputed rents... (Fisher 1978, p.27).

In the course of uncertainty resolution during a development process, teamwork among specialists can also lead to improved communication or other "group skills." The development of the transistor provides an example. It was preconditioned by certain scientific knowledge and simultaneous progress in several fields of investigation; this involved collaboration among an interdisciplinary team of physicists, chemists, metallurgists, and engineers (Braun and MacDonald 1979, Ch.4).[14] Technological development often requires the coordinated talents of a large number of highly specialized individuals. Such teamwork is also needed to carry out tasks outside the technical sphere.

It should be kept in mind that the transistor was developed during an era in which tax policies and the availability of venture capital were considerably different than they are today. The above analysis suggests the need for a new tax policy initiative compatible with today's circumstances: it may be desirable to implement a personal income tax credit affecting all individuals employed by the most R&D intensive firms. Such a personal income tax credit would serve several purposes. First, the initial impact would be to increase the take-home pay of all individuals employed in highly R&D intensive firms. These could be firms with higher than the median expenditure on R&D, expressed as the percent of sales for the last 2 years; alternatively two levels of tax credit could be instituted for employees of firms with R&D expenditures greater than, say, 4% and 7% of sales, respectively. Since employment security in such firms is generally lower than in other sectors of the economy, this tax credit could be considered compensation for additional risks that may not be compensated at prevailing wage rates in current labor markets, especially in the case of smaller and newer R&D intensive companies. Second, since labor markets may not compensate for such risks currently, there is little reason to believe that the full increase in take-home pay would remain with labor after the marketplace has a chance to adjust to this new tax initiative. Gradually the effective wage rate paid by the firms would be reduced. This would provide an incentive for firms to keep R&D commitments high enough to qualify their employees for the personal income tax credit. The tax credit's effect on wage rates paid might also encourage firms to invest in labor productivity enhancement, if the elasticity of substitution is sufficiently high. Of course, there would be attempts by firms to reclassify expenses as R&D in order to qualify their employees for the credit. Such problems require serious attention, but as Hufbauer has argued, they are not necessarily insuperable (Industrial Technology 1978, p.122).

Clearly, further research would be useful to verify the correctness of these observations and to determine the appropriate magnitude of such a tax credit. If this tax initiative were part of a larger tax revision package for technological innovation that encouraged greater availability of venture capital, such a proposal might be particularly beneficial to newer and smaller firms (which tend to be more labor-intensive). It would also avoid the perverse distribution implications of many capital gains tax proposals, which tend to provide tax relief mainly in high income tax brackets (Musgrave 1978). The personal income tax credit proposed here is a possible way to encourage the "bearing of risk" that is widely recognized as an important element

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[14] Some team members eventually left and formed their own companies. Similarly, Control Data Corporation was formed in 1957 by a group that had been part of Sperry Rand's Univac Division (Harman 1971, p.19).

of technological innovation. As has been argued on a previous occasion, "When individuals (in management, in labs, in production, in sales, etc.) must operate in a world fraught with risk and uncertainty to achieve such innovation—especially when they must rely on their creative ideas to ensure the success of their enterprises—they must be allowed generous compensation for the activities that bring their ideas to fruition" (Industrial Technology 1978, p.15). This subject will receive further consideration at the conclusion of this paper.

Returns to R&D and Associated Investments

It is very difficult to acquire the detailed information necessary to make careful calculations of the returns to R&D or related investments required in the process of technological innovation. In an earlier study of the computer industry, it was possible to estimate econometrically the responsiveness of product quality change to investments in R&D by firms (Harman 1971). This analysis confirmed that some of the smaller and newer firms had quite effective R&D efforts. However, product quality is not a measure of profitability; in fact, success in the computer industry has often been attained by a shrewd choice of product design that avoided an ambitious push to the limits of technical feasibility (Harman 1971, Ch.4). On the average, one would expect that returns from this type of investment would be higher than the average for the industrial sector because of the risks inherent in R&D. The risks are well illustrated by GE and RCA, neither of which were able to profitably participate in the computer industry in the mid-1960s (Harman 1971, pp.16-17, 22-26). The process technology of transistors provides another example; it changed so rapidly that the original innovator—Philco—soon dropped out of the industry with a large, unprofitable capital investment in what rapidly became obsolete production equipment (Braun and MacDonald 1978, pp.142-3).

The recent path-breaking research of Mansfield and his colleagues, in measuring not only the private but also the social rates of return from industrial innovations, sheds new light on this topic. However, their research involves a nonrandom sample of seventeen innovations that do not necessarily represent the results of activities in the electronics sector.[15]

Mansfield and his team found that the social rate of return from industrial innovation has been very high—the median is conservatively estimated to be over 50 percent. However, they also found that the private rates of return from these investments have been much lower. In nearly a third of their cases the private rate of return was so low that "no firm with the advantage of hindsight, would have invested in the innovation, but the social rate of return from the innovation was so high that, from society's point of view, the investment was well worthwhile" (Mansfield et al. 1977, p.235). These authors point out, however, that for a number of reasons such results have little bearing on whether there is an underinvestment in innovative activities.

Tax Policies

Knowledge about the "real world" returns from investments in technological innovation is in very short supply. Representatives from the semiconductor industry have uniformly and fervently argued for a more favorable tax structure to encourage such investments. Heilmeier, for example, has pointed out specific sections of the tax statutes and regulations that he believes either are a disincentive to perform R&D or an encouragement to U.S. firms to transfer more R&D to foreign countries. He further points out that "government agencies have no way of reviewing the regulations in the light of their impact on development of U.S. technology and innovation" (Heilmeier 1978, p.21). Perkins points out the difficulty of hiring and retaining

[15] The one innovation that is identified as a new electronic device is the only one of their sample that produced a negative rate of return both in private and social terms (see Mansfield et al. 1977).

entrepreneurial managers subsequent to the removal of special tax treatment for the "qualified stock option." Without this form of stock option the manager recruited to a new enterprise must pay a capital gains tax on stock upon exercising this option, even if the gains he achieves are illiquid unless he sells his stock (Perkins 1978, p.43).

Although the Revenue Act of 1978 restored some of the capital gains tax incentives removed by the capital gains taxes of 1968 and subsequent years, industry can legitimately claim that the tax environment for venture capital availability and risky investments has deteriorated over the last decade. At the same time, the National Science Foundation has reported that nearly 40 percent of the R&D activity in private industry is financed by federal funds (some 10 billion dollars in 1977). Hufbauer has reported that, "in addition, Section 174 of the Internal Revenue Code, which permits the immediate expensing of R&D outlays on salaries and expendable supplies (but not capital equipment), entails a modest incentive by comparison with the conceptual alternative of capitalizing and amortizing all R&D outlays. The value of this incentive in 1977 was about $1.4 billion" (Hufbauer 1978, p.18). Kaplan and his colleagues summarize a set of studies of tax policies for R&D and technological innovation by noting that foreign countries often provide more generous tax incentives for R&D than does the United States; however, such problems as the difficulty of rewarding new R&D activities versus simply subsidizing already existing ones, and undesirable distributional problems suggest to them that "a program of direct government support of innovation is preferable to tax incentives. Of course, it must still be demonstrated that the government can devise a program of direct support that operates with as little red tape and delay as many tax incentive schemes" (Kaplan et al. 1976, p.18).

In the absence of strong empirical support for the claim that the market is failing to provide adequate incentives, the best evidence of the need for policy initiatives comes, perhaps, from the political decision to initiate the Domestic Policy Review on Innovation; further evidence may be derived from the fact that the results of the Review led President Carter and his principal advisors to initiate some specific decisions and legislative recommendations that were expected to "have a significant impact" and to "provide a signal to the private sector that innovation is valued and that it is federal policy to preserve and promote it in the years ahead" (Carter 1979, p.1). The proposals were not widely regarded as significant (see Stanfield 1979), and all tax policy changes affecting industrial innovation were explicitly deferred, to be considered later in the context of broad fiscal policies.

Regulatory Policies

In addition to strong support for a more favorable tax environment, firms in the electronics sector have been concerned about the expanding regulatory activities of the federal government. For example, a president of a semiconductor firm has stated:

> Desirable as favorable tax policies are, however, they would fail to stimulate innovation if they were hamstrung by the usual government demands for reports, studies, and impact statements. There is also some hazard that favorable treatment would be available only for 'socially desirable' technologies, adding endless cost and complexity to defending technology proposals.

One of the President's nine areas for specific decisions regarding innovation is "improving our regulatory system." This includes greater emphasis on performance standards (rather than design or specification standards) for the Environmental Protection Agency, as well as the implementation of "innovation waivers." To help reduce regulatory uncertainties for industry, five-year forecasts of their priorities and concerns are to be prepared by health, safety, and environmental regulatory agencies. One of the latest (and perhaps most dubious) actions is the decision to have executive agencies develop and implement a system of priorities for expediting review of the safety and efficacy of products that "are most innovative and/or have exceptional social benefits." Such attempts at forecasting or a priori assessments of the social desirability or undesirability of innovations is, at best a highly uncertain undertaking—especially for the more "basic" innovations that have both large positive and negative impacts. Kuznets, for example, has pointed out that there are long chains of sequences of impacts associated with basic innovations—from the development of "useful knowledge and science to technological innovation, to growth in productivity to changes in structure of production, to changes in other aspects of economic structure, to changes in political and social structure and beliefs, and back again to changed conditions of life and work..." (Kuznets 1971, p.349).

One of the characteristics of such long sequences is "the near impossibility of making a complete and relatively reliable prediction of the long-term consequences of a given major technological innovation ... to foresee not only the favorable or neutral, but also the adverse consequences" (Kuznets 1971, p.356). To illustrate the point, Kuznets poses the following question:

> Was it foreseen, or at the time predictable, that the spread of the motor car, by inducing migration of the middle and high income groups from the cities to the dormitory suburbs, would result in a breakdown of the urban tax base and lead to a near-collapse of effective municipal government—with all the ensuing problems with which major cities in the United States are presently struggling? ...If a prediction had suggested the problem to be created in two or three decades by traffic congestion in the cities, the impulse to an immediate counteracting policy would have been weakened by the argument that there's plenty of time and conditions may change. ...In view of the limited capacity of society to deal with the many problems needing solution, the lag in the attempt to avoid or inhibit the long-term undesirable structural change is almost inevitable. (Kuznets 1971, pp.352-353).

This is not to say that social costs of technological innovations are to be ignored! A recent example of the ability of the U.S. government to take action in this regard was spurred by the growing concern over the computer information processing and storage capabilities and personal privacy. The Privacy Act of 1974 created the Privacy Protection Study Commission, which has held hearings on the major types of personal information and record systems that currently exist; i.e., research/statistical, employment, personnel, medical, insurance, depository, and credit. Some of the public policy issues uncovered by this review include: (1) Do we need a right-of-ownership status for personal information? (2) Does factual information need to be distinguished from subjective and conjectural information? (3) Should information collected to make a determination (and with no perceived future need) be distinguished from information needing to be kept? (See Ware 1976.)

Competition and Selection Environments

Competition plays a central role in all of the conceptual formulations of the innovation process discussed above. The term "competition" does not refer simply to price rivalry in a commercial marketplace. A fundamental form of competition in technological innovation concerns the ideas that are considered worth pursuing within a firm. Such competition involves both the technical and economic aspects of new design concepts, and is usually sustained well into the development process. For example, when a new system is under development at IBM, program managers for current lines are encouraged to look for ways to expand the capabilities of their products. Although limited development resources are devoted to such activities, IBM is careful not to cut off such competition. Current programs contending with new development efforts provide a type of insurance for the firm (Harman et al. 1977, p.36).

In the computer industry, there have been opportunities at many stages for choices among competing component technologies. The successful development of the transistor did not automatically lead to the replacement of vacuum tubes. Rather, it depended on the economics of production. The character of quality change of product-oriented technological innovation depends on the types of final users that are to be considered. For the development of the transistor, its capability and price relative to the vacuum tube were considered by computer developers and manufacturers; in contrast, performance capabilities (including reliability and ease of maintenance), as well as price are the principal dimensions for assessment by computer users—virtually regardless of the components used in the design. Still, the development of quantitative measures of user-oriented product quality dimensions that remain reliable over time is indeed a difficult undertaking.[16]

For other forms of competition, public policy plays a more prominent role. Let us consider the industry perspective. As Tilton (1971) implicitly points out, Klein's "hidden foot" rivalry has played a very important role in the semiconductor industry:

> The market structure of the semiconductor industry (in the United States, Britain, France, Germany, and Japan) ...is such that established firms are promptly disciplined or replaced when they fail to act quickly. (Tilton 1971, p.48, see also Klein 1977, pp.128-133.)

In contrast, European countries have pursued consolidation policies within their computer industry and have fared much less successfully. Perhaps it is fortunate that Europe did not follow Servan-Schreiber's urging: "The logical policy for Europe would be to pool all the resources we can muster—probably from a British nucleus with immediate support from French, German and Dutch industry—into a unified effort, while blocking off some outlets for our own products. Only with a market of this size can we hope to compete with the Americans between now and 1980" (Servan-Schreiber 1967, Ch. XIV).

Antitrust Policies[17]

For several reasons government antitrust policies have been effective in promoting rivalry among U.S firms. Through a consent decree ending the Justive Department's suit against IBM in 1956, IBM was required to sell its machines as well as to rent them. This led to greater competition in the sale of computer services and encouraged the development of this branch of the information processing industry (Harman 1971, p.13). Similarly, an antitrust suit against ATT initiated by the Justice Department in 1949 was finally settled by a consent decree in 1956 that led to a substantial shift in the dissemination of ATT controlled patents—all existing patents were to be licensed royalty free by Western Electric to any interested domestic firm (although Western Electric could ask for a cross licensing provision) and all future patents were to be licensed for "reasonable royalties." On patents for semiconductors, royalties were generally set at no more than 2 percent of sales (Tilton 1971, pp.73,74,76). These new licensing policies—implemented by the firms under government pressure—set a standard that encouraged the diffusion of technology and "hidden foot" rivalry, which supported a continued rapid rate of technological innovation.

[16] For elaboration of this point, see Harman et al. 1977, Linstone and Sahal 1976.

[17] The still pending U.S Justice Department antitrust case against IBM is a matter that will not be dealt with in this paper.

Procurement Actions and New Entry

For both the semiconductor and computer industries, the early development of the government market was an important stimulus for product innovation.[18] Tilton has discussed the link between qualitative improvements in semiconductors over time and the various end-users of the product; he attributes much of the stimulus for rapid innovative advances in product quality, as well as rapid diffusion of innovations throughout the U.S. industry, to demanding government requirements. Utterback and Murray (1977) concluded that government procurement provided a more important stimulus to the civilian electronics industry than did direct support of R&D (although government procurement has since lost much of its significance for this sector).

Government procurement has also played a useful role in encouraging new firms to enter these industries, although there is little evidence that such a policy has been deliberate or has recognized the important role that entry or the threat of entry plays in stimulating technological innovation. (See, for example, Baumbusch and Harman 1977, pp.47-50, 53-56; and Baumbusch et al. 1978, pp.56-62.)

In a very pragmatic and insightful discussion of ways of diagnosing the existence of monopoly, Fisher concludes that the role of entry is particularly important. He states:

> "..whether considered as a phenomenon of new firms coming into the business or a phenomenon of older firms able to expand ... the analysis of entry conditions is the analysis of a central phenomenon which places or does not place constraints on the behavior of the alleged monopolist. It is therefore with some regret that I have to say that the analysis of barriers to entry is, in my view, the single most misunderstood topic in the analysis of competition and monopoly (Fisher 1978, p.28.)

The availability of venture capital also helps to encourage the threat of new entry. In this regard, President Carter's Industrial Innovation Initiative–dealing with both fostering and development of small innovative firms and opening federal procurement to innovations–are small steps in the right direction. The income tax credit proposed in this paper would also be useful in this context, since new firms would have especially high R&D/sales ratios while initial sales are low. Further policy consideration of the role of new entries in stimulating technological innovation is warranted.

International Economic Policies

Finally, competition in the context of world markets merits some discussion. One issue concerns the protection of domestic markets from foreign competition through tariff or non-tariff barriers. One does not have to follow the trade press very closely to know that the semiconductor industry has been unhappy with the recent situation. An executive in a semiconductor firm has described his concerns in the following terms:

> U.S. companies can compete against any foreign manufacturer if we have Free Trade on an equal basis. This means that both Tariff and non-Tariff barriers in Japan and Europe need to be removed or equalized. This is particularly true of Japan where import duties for U.S. companies are considerably higher than U.S. duties for Japanese products and non-tariff barriers keep U.S. semiconductor products from being used in certain markets such as Telecommunications; it is also going to be very

[18] Tilton 1971, Ch.4; Harman 1971, Ch.2; see also the statements by Heilmeier and Corrigan in Industrial Technology 1978.

> important that two tier pricing as employed by the Japanese (lower U.S. prices than in their own markets) not be tolerated and a mechanism set up to quickly impose penalties on foreign semiconductor manufacturers (before the damage is done) who operate with a two tier price scheme.

Although such concerns are serious, the solution is not to establish retaliatory barriers; competition at many levels (even from foreign sources) fosters further technological innovation, and there is clearly room for further advances in semiconductor technology (see Sutherland et al. 1976). Although the Tokyo round of the General Agreement on Trade and Tariffs (GATT) has made some progress in the areas of tariff and nontariff barriers, the macroeconomic effects for the United States are likely to be very small.

The transfer of technology and limitations on direct ownership of foreign operations have been important in both the computer and semiconductor industries. Japan in particular has orchestrated a set of government policies that have proven very beneficial to their domestic industries. These issues have been treated elsewhere (Harman 1971, Tilton 1971), but may be useful topics for further consideration, since they fall outside of the GATT framework. Similarly, it may be useful to consider more carefully the relationship between the parties to GATT and centrally planned economies.

IV. REPRISE: THE POLICY PROPOSAL

Policy recommendations should follow from the identification and clarification of a problem. But, as suggested at the outset, the understanding and shaping of the process of technological innovation is progressing more like the gropings of a lobster's claws than the coordinated fists of a boxer.

In the "left claw" we have insights from theoretical analyses (as sketched in Section II rather selectively from a vast amount of relevant research); these can be summarized as follows:

1. Innovation may be seen as a process of uncertainty reduction in response to a final demand, based on private or public needs.
2. Neoclassical economic theory provides insights into changes "at the margin" from influences such as changes in prices of goods or inputs; such theory is well developed but not entirely adequate for dealing with uncertainties and shedding light on the processes through which predicted outcomes occur.
3. The evolutionary theory of Nelson and Winter (1977) provides, at least, a useful vocabulary for understanding the process.
   a. Natural trajectories of technological innovation depend for "next steps" on the present status of the firm and are based on underlying scientific progress that is not altered rapidly by reallocation of resources.
   b. Selection environments, involving both market forces and bureaucratic/political decisionmaking, determine the success of innovations and contribute to shaping the innovation process.
4. The dynamic theory of Klein (1977) attempts to build on the biological metaphor of considerable experimentation and diversity by firms, as a response to uncertainty at the micro-economic level, leading to stability and rapid progress at the macroeconomic level; lagging individual firms suffer the "hidden foot" feedback of loss of market share, with the threat of such feedback spurring others on to further innovation.
5. International consequences of technological innovation, as well as of the relative availability of productive inputs and raw materials, are becoming increasingly important for domestic progress (Hufbauer 1970).

The "right claw" of the lobster is grasping for facts about the world (as reviewed in Section III) that one should be cognizant of when considering policy options; these may be briefly described as follows:

1. Uncertainty, Ideas, and Imperfect Appropriability (personal gratification). There are individuals involved throughout the process of creating and adapting new products and services, many of whom enjoy the challenges of uncertainty resolution. All potentially suffer from a lack of job security and an inability to capture the complete returns of their contribution to the creative (and profitable) efforts of their teams and firms.
2. Returns to R&D and Related Investment (corporate gratification). Due to the risks and uncertainties of the innovation process, returns to R&D and related investment have been high in many cases, but the meager empirical evidence which is available (Mansfield et al. 1977) suggests that private returns are still less than social benefits, and may in some cases be less than the private returns of less risky activities.

3. Competition and Selection Environments (societal gratification). Where markets can be relied upon to transmit society's needs, efficient production and stimulation of future innovation occurs (subject, of course, to the feasibility of capturing adequate returns). Selection environments involving direct or indirect involvement of bureaucratic/political processes for the full articulation of societal needs are widely perceived to be (at times) inimical to innovation, and can potentially undermine competitive positions internationally.

By such "clawing" at the complex and rapidly changing world into which government actions extend, has it been demonstrated that a "market failure" is occurring, of sufficient dimension to outweigh the inherent costs of government action to implement remedies (Wolf 1979)? The answer is no. Nor have the far more extensive efforts of the President's Domestic Policy Review in the United States and considerable related contemporary research shown that such a failure is occurring. Limits of current knowledge and uncertainties about the world are too great to allow an unambiguous signal for action.

Under such circumstances it may be best to rely on a broader perspective when reviewing evidence of the need for policy action. Technology and innovation have been principal ingredients in American economic development for more than a century, and this pattern was exhibited by the United Kingdom earlier. In recent times, technology has contributed to the important standing of American industry in world markets; technology-based American firms have provided a large portion of the foreign earnings used to obtain important raw and processed materials from abroad. But there is a concern about declining international competitiveness; the undiagnosed decline in the United Kingdom's competitiveness during the period from 1890 to World War II illustrates the risks of inaction. Although employment impacts of technological change have not been as severe in the United States as they seem to have been in Europe (Rothwell and Zegveld 1979), rigidities in labor markets have been identified as "the heart of developed countries long-term problems" (Interfutures 1977, p.170). Moreover, the President's extended Domestic Policy Review on Industrial Innovation has encouraged expectations that important policy actions would follow.

Suppose we assume for the moment that the preceding brief review of theory and evidence provided a sufficient case for action. Still, many possibilities exist (see Figure 2). Even if the goals of many of these potential policy actions would enjoy broad political agreement, the mechanisms of policy implementation often can be cumbersome and counterproductive.

Thus, instead of evaluating a wide range of alternative policies (some of which have been implicitly endorsed or dismissed in this paper), one tax policy is proposed here and evaluated in the context of the theoretical and empirical insights reviewed above:

> PROPOSAL: Grant a personal income tax credit of, say, 10% to each individual earning income from every highly R&D-intensive, for-profit firm.[19]

Let us first consider the immediate effect of this tax policy—the after-tax wages and salaries of individuals employed in companies that invest heavily in R&D would rise, regardless of the economic sector in which they are employed. One of the most important arguments for stimulating innovation through tax policy is that government agencies need not be directly involved in the decisionmaking on how the proceeds of the indirect subsidy are to be used.

[19] See Section III for a sketch of some of the possible alternative formulations of such an income tax credit, and for a suggested definition of "R&D intensive." Of course, the mechanism for implementing such a policy could be as easy as allowing qualified firms to print an asterick (or other suitable identifying mark) in the appropriate place on their employees' W-2 forms. Clearly, this proposal could be enacted as part of a larger tax proposal so that the overall fiscal effect could be neutralized or tailored to the explicit purposes of a comprehensive fiscal policy.

Policy Mechanism	Impact On: Industrial Innovation process	Feedback from Market: Domestic	Feedback from Market: Export
General			
Technical Information Dissemination	x		
Direct Support for Basic Research (e.g., NSF, NIH)	x		
Support of Advanced Education (including University/Industry Cooperation)	x		
Patent Policies	x		
Tax and other Fiscal Policies	x	x	
Monetary Policies	x	x	
International Economic Policies			
-- trade		x	x
-- treatment of multinationals		x	x
Sectoral			
Direct Support of Developments (e.g., Agriculture, DOD, NASA)	x		
Procurement Actions		x	
Regulatory Policies			
-- anti-trust	x		
-- environmental, health, and safety	x	x	
-- COCOM restrictions			x

Figure 2. Policy-analytic framework for viewing government impacts on technological innovation.

Since a firm does not have to make new capital investments to qualify, new and small firms may benefit even during times of tight monetary policies. The salary increases would provide a signal to the labor market of the types of firms that are likely to provide attractive job opportunities in the future.[20] It will be recognized that if job security is lower in such companies, some compensation would be provided by the government in the form of higher current income. This amounts to a recognition of the "personal gratification" issues noted above.

After a time, there would be labor market adjustments to this new tax credit. For some occupations and activities (especially the unskilled and some semi-skilled ones), it is suspected that the wages paid by the R&D-intensive firms would be less than standard market rates in various geographical areas—the firms could capture some or all of the tax credit as indirect wage subsidies! Is this undesirable? Certainly not, if we expect such firms to be as competitive as possible in regional, national, and world markets. They must be encouraged to be as cost-conscious as possible. The proceeds of these subsidies could be used by the firm to hire more labor or to invest further in R&D, in capital equipment, or elsewhere as the firm sees fit[21]—subject to the multitude of regulatory and other government "guidance" to the firm, and to the future discipline of the marketplace.

In addition, existing firms whose employees do not quite qualify for the income tax credit will come under pressure to invest more heavily in R&D. There are many uncertainties (and even hopes) about the outcomes of such efforts, but one thing is certain—some firms will try to redefine their expenditures to give the appearance of more R&D. Control of cheating is a difficult problem for many economic and social policies. No announced policy of selective enforcement would be desirable, but if large firms are carefully scrutinized, the laxer enforcement of small firms could act as a form of compensation for the relatively larger burden they shoulder in complying with regulatory policies. In any case, if such firms expand they would become more vulnerable to closer scrutiny, and presumably to sizable penalties for cheating.

For these reasons, the long-term and indirect effects of this proposal would be to subsidize R&D-intensive (and especially smaller and more labor intensive) firms, with the proceeds of the indirect subsidy remaining relatively unrestricted. This responds to the need for "corporate gratification" as discussed above.

What about the benefits to the larger society—what has been called "societal gratification"? If there is one message in this paper, it is that investments in R&D and the larger process of technological innovation is an inherently uncertain process. There are no guarantees. But if history is any guide, such a policy should help stimulate the creation of new products, the reduction of prices of many existing products, and perhaps even a more widespread public appreciation of the increased security and societal stability gained through encouraging some of its individual members to take innovative risks.

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[20] This point also relates to national security considerations, since the employees of many firms receiving R&D funding from the Department of Defense would quality for this tax credit. In a recent study, Defense Industrial Planning for a Surge in Military Demand, we found that "firms repeatedly emphasized that the most severe problems in meeting surge demands would relate to the hiring of appropriately skilled labor and the timely acquisition of additional equipment, with the former receiving the most emphasis from both current and noncurrent defense producers." (Baumbusch et al. 1978, p.62, original italics).

[21] See the Appendix for an analysis of some of the issues raised here.

APPENDIX

A SIMPLE NEOCLASSICAL MODEL OF INDUCED TECHNOLOGICAL INNOVATION[22]

Suppose the cost of process-oriented technological innovation E_t, is a function of (T_t/T_0) where T_t represents the level of technology at time t. And, to simplify the analysis, assume that there is no cumulative advance—every period starts off from T_0 (otherwise T would be viewed as a form of capital, needlessly complicating the point at issue here). Thus we assume that: (a) "systematic" R&D expenditure, E_t, can be directed toward technology relevant to the firm's production, and (b) firms have to pay for their own technology; i.e., no transfers occur from outside the firm.

Assume a production function homogeneous of degree 1 in the usual inputs, labor and capital,

$$q_t = f(L_t, K_t; T_t) \tag{1}$$

[22] This material draws heavily on a textbook formulation of this subject by Becker (1971, Lecture 27.)

and

$$q_t = L_t MP_{Lt} + K_t MP_{Kt}$$

where

$$MP_{it} = \frac{\partial f(\ )}{\partial i}$$

Furthermore, assume that T has a stable impact on marginal products of the factors of production; we can define

$$a_{it} \equiv \frac{MP_{it}}{MP_{io}}$$

Then

$$q_t = L_t(a_{Lt} MP_{Lo}) + K_t(a_{Kt} MP_{Ko}) \qquad (2)$$

where $T = T_o$ for MP_{io}. If $T_t > T_o$, $MP_{it} > MP_{io} \Rightarrow a_{it} > 1$.

The process innovation cost function thus could be represented as

$$E_t = g(a_{Lt}, a_{Kt})$$

where

$$\frac{\partial E_t}{\partial a_{it}} \equiv g_i$$

and g_i is the marginal cost of innovations yielding i^{th} factor productivity enhancement. We could also rewrite the production function by representing T_t by its influences on the marginal products.

$$q_t = F(L_t, K_t; a_{Lt}, a_{Kt})$$

To minimize total cost—production and "R&D"—the firm will operate so that

$$MC = \frac{w}{\partial q_t / \partial L_t} = \frac{v}{\partial q_t / \partial K_t} = \frac{g_L}{\partial q_t / \partial a_{Lt}} = \frac{g_K}{\partial q_t / \partial a_{Kt}} \qquad (3)$$

where w and v are the wage rate and the cost of capital services respectively. From equations (1) and (2)

$$\frac{\partial q_t}{\partial L_t} = MP_{Lt} = a_{Lt} MP_{Lo}$$

and similarly for MP_{Kt}. Also

$$\frac{\partial q_t}{\partial a_{Lt}} = L_t MP_{Lo}$$

and similarly for a_{Kt}. Substituting into equation (3), we have for L and a_L

$$\frac{w}{a_{Lt} MP_{Lo}} = \frac{g_L}{L_t MP_{Lo}} \qquad (4)$$

The resulting optimal a_{Lt} is

$$a_{Lt} = \frac{wL_t}{g_L}$$

Optimal choice of enhancement of the marginal product of labor input (relative to the base period) will be equal to the ratio of total expenditure for Labor (the wage bill and not simply the price of labor, as is sometimes argued) to the marginal cost of increasing its productivity. A similar result can be derived for a_{Kt}.

Interpretations:

1. Technological innovation will be "factor neutral" if marginal improvement costs are proportional to expenditures on factors, i.e., $a_{Lt} = a_{Kt}$ if

$$\frac{wL_t}{g_L} = \frac{vK_t}{g_K}$$

Otherwise, technological innovation will be "biased toward" the factor whose "improvability costs" (g_i) are low relative to the total expenditure devoted to that factor. From a public policy point of view, actions (e.g., tax policies) that tend to lower a factor price paid by the firm would encourage the firm to invest more heavily in improving that factor's productivity, provided that the elasticity of substitution between factors is greater than unity. This interpretation is important to the personal income tax credit proposed in this paper.

2. Higher q would merit higher E—larger firms will invest (or invest more) in R&D because there is a larger production volume (and hence a larger amount of factor inputs) which can benefit from the enhanced marginal productivity of factors. These increased R&D expenditures need not arise because of differential access to financial markets or other forms of monopoly power.

The model presented here, of course, does not account for a variety of opportunities to make advancements in different phases of the R&D process, nor does it consider the market imperfections which exist in many technology-intensive industries. However, it does illustrate the kind of insights that can be derived from the necessarily stringent "as if" assumptions of the neoclassical theoretical framework. Here, a word of caution is in order:

> Our predictions of the operations of markets and of the economy are sensitive to our assumptions about mechanisms at the level of decision processes. Moreover, the assumptions of the behavioral theories are almost certainly closer to reality than those of the classical theory. These two facts, in combination, constitute a direct refutation of the argument that the unrealism of the assumptions of the classical theory is harmless. We cannot use the in vacua version of the law of falling bodies to predict the sinking of a heavy body in molasses. The predictions of the classical and neoclassical theories and the policy recommendations derived from them must be treated with the greatest caution. (Simon, 1979, p.509).

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