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The Transfer and Diffusion of New Technologies: A Review of the Economics Literature

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THE TRANSFER AND DIFFUSION OF NEW TECHNOLOGIES: A REVIEW OF THE ECONOMICS LITERATURE

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ABSTRACT

This report presents a general overview of the economics literature on technological change and focuses particularly on the interface between the public and private sectors in promoting the transfer and diffusion of new technologies.

Our ability to transfer and diffuse new technologies is generally recognized as a key to increased productivity in the United States and this country's ability to compete internationally. A great deal of research has been done on technology transfer and diffusion by various disciplines and from numerous perspectives. Unfortunately, the policy implications of those different works are not always consistent. Further, the different disciplines have difficulty in communicating even when addressing the same issues and drawing the same general conclusions.

The primary objective of this report is to lessen the chasm among the disciplines with respect to technology transfer and diffusion by summarizing the perspectives presented in the economics literature. The document is intended primarily for an interdisciplinary audience.

The discussion begins with an overview of the economics literature on technological change and focuses on what economists commonly refer to as the Schumpeter trilogy -- i.e., invention, innovation, and diffusion. Economists typically view technological change to occur in these three distinct steps and have formulated conceptual frameworks that suggest how and why each step in the process of technological change takes place. After defining these three steps, the report presents brief overviews of the seminal conceptual and empirical works in the three areas. Of key concern is an overview of the types of questions historically posed by economists and the degree to which economists have reached a consensus on these questions.

The report then abstracts from this larger picture of technological change and focuses specifically on the interface between the public and private sectors. Within this second thrust, the report poses and attempts to answer two general questions: (1) Why have economists argued for government involvement to promote technological change? This issue leads to a brief discussion of market failures that inhibit the invention, innovation, and diffusion of new technologies. (2) Where and how can the public sector interface with the private sector to correct the market failures or, alternatively, take actions to counteract the effects of market failures?

The role of the federal government in the innovative process remains the subject of significant debate by economists. Although most economists would agree that some role must be played by the public sector, our current conceptual and empirical knowledge is lacking. Little consensus has thus been reached about how the government should respond to the problem in general, and even less consensus exists about how particular technologies in particular markets should be dealt with.

The report suggests that the public sector can encourage the process of innovation by either directly participating in the process of technical change or by indirectly stimulating the private sector's innovative activities. Although both methods have been shown to promote technical change, economists have not yet developed a generally agreed upon formula that dictates what method is most appropriate in any given case.

It is likely that the arguments by economists with respect to the government's role in technological change will become more definitive as more detailed conceptual and empirical studies are completed. It is unlikely, however, due to the number of dynamic factors that are known to influence the innovative process, that the economics profession will develop a formula or set of formulae for promoting technical change or the involvement of the public sector in that change. A movement toward interdisciplinary research, which is currently underway, is the most promising avenue for studying the role of public policy in promoting technical change.

1. INTRODUCTION

Our ability to transfer and diffuse new technologies is generally recognized as a key to increased productivity in the United States and this country's ability to compete internationally. A great deal of work has been done on technology transfer and diffusion by various disciplines from numerous perspectives. Unfortunately, in examining that literature, one is struck not only by the different policy recommendations made with respect to particular issues, but also by the obvious inabilities of the different disciplines to communicate even when addressing the same issues and drawing the same general conclusions.[1]

A primary goal of this report is to lessen this chasm among the disciplines with respect to technology transfer and diffusion by summarizing the perspectives presented in the economics literature on the subject. Although intended for an interdisciplinary audience, the content of the report will also hopefully be of value to the economist interested in an overview of the subject.

A primary focus of this work is on the interface between the public and private sectors in the transfer and diffusion of new technologies developed within or facilitated by the public sector. The specific policy instruments that can be used to facilitate the transfer and diffusion process are discussed with respect to their specific pros and cons. Also discussed are the policy instruments available to facilitate the transfer and diffusion of new technologies developed within the private sector.

A secondary focus of this report is on the major thrust areas addressed by economists with respect to the broader issues associated with the innovative process. This general discussion is important because it not only suggests the types of issues believed to be important by economists, but also why those issues are argued to be important. The general discussion also contributes to a better understanding of why specific policy instruments have been advocated by economists. It is not, however, the purpose of this report to provide a definitive review of the economics literature on the general topic of innovation. Rather, the general discussion is provided as a means to focus on the more narrow topic of the public/private interface to transfer and diffuse new technologies.

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[1] A good example of our inabilities to communicate across disciplinary lines is illustrated when reading the National Science Foundation's (1983) so-called "Red Book."

2. APPROACH

The discussion begins with an overview of the economics literature on technological change and focuses on what economists commonly refer to as the Schumpeter trilogy--i.e., invention, innovation, and diffusion (see Stoneman, 1983). Economists typically view technological change to occur in these three distinct steps and have formulated conceptual frameworks that suggest how and why each step in the process of technological change takes place. After defining these three steps, the report presents brief overviews of the seminal conceptual and empirical works in the three dimensions of technical change. Of key concern is an overview of the types of questions historically posed by economists and the degree to which economists have reached a consensus on these questions and their answers.

The report then abstracts from this larger picture of technological change and focuses specifically on the interface between the public and private sectors. Within this second thrust, the report poses and attempts to answer two general questions: (1) Why have economists argued for government involvement to promote technological change? This issue leads to a brief discussion of market failures that inhibit the invention, innovation, and diffusion of new technologies. (2) Where and how can the public sector interface with the private sector to correct market failures or, alternatively, take actions to counteract the effects of market failures? It is argued that government intervention can take two main avenues--(a) by regulating the private sector and thereby altering private-sector incentives and disincentives such that the private sector itself performs the function of technological change in a way that is closer to the social optimum; and (b) by the government itself participating directly in technological changes, or, in other words, by having the government participate directly in the invention, innovation, and/or diffusion steps. If the public sector takes the regulatory approach, numerous policy instruments are available to address the relevant market failures. If the public sector takes the second approach, the government's activities must eventually interface with the private sector if those activities are to be realized as technological progress in the private sector. Appropriate considerations are the relative advantages of different policy instruments and the point--i.e., invention, innovation, or diffusion--at which the interface should occur.

3. OVERVIEW OF THE ECONOMICS PERSPECTIVE ON TECHNOLOGICAL CHANGE

3.1 THE SCHUMPETER TRILOGY

Economists typically think of technological change as occurring in three phases commonly known as the Schumpeter Trilogy--i.e., invention, innovation, and diffusion. Invention, which is often depicted as an exogenous occurrence, refers to the generation of a new idea or new concept that may lead to a new product or process. Innovation follows invention and is said to be accomplished when (1) the idea from invention is developed into a new product or process, and (2) the new product or process is first commercially transferred. Diffusion refers to the process by which the new process or product spreads across firms within a market and across markets.

Schumpeter's work and the resulting steps of technical change were focused on the relationship between market structure and technical change. Schumpeter (1947) postulated that concentrated industries were more suitable for rapid technical change. Monopolies were argued to be better able to bear the risks of an uncertain innovation process and have the resources for a sustained research effort. Since Schumpeter's seminal piece, numerous theoretical and empirical studies have addressed these basic questions. Unfortunately, no consensus has emerged on whether to accept or reject the Schumpeter hypothesis. The main reason for the continuing debate is a lack of R&D data. We address the notion of market structure and technical change further below. At this point we focus on the conceptual and empirical economics literature that has addressed the three steps in the Schumpeter trilogy.

3.2 INVENTION AND INNOVATION

The general theories of invention and innovation fall into two broad categories--neoclassical theory and evolutionary theory. Neoclassical theory asserts that invention and innovation occur as a result of the drive for maximum profits.[2] Firms are said to innovate[3] in response to two types of forces--demand pull and technology push. Demand-pull technological change occurs when innovators respond to the perceived needs of the market. For example, a firm's marketing department supposedly identifies technological needs and directs the development of new technologies in response to those needs. Potential profitability from the new product or process provides the incentive for the firms to innovate under the demand-pull hypothesis. The demand-pull hypothesis suggests that

[2] The proponents of neoclassical theory of technical change include Arrow (1962) and Kamien and Schwartz (1974 and 1976).

[3] Here we are using the term innovate in the generic sense to include both invention and innovation.

firms with large marketing and research facilities have advantages over firms with smaller marketing and research facilities.

Technology-push technical. change occurs because of a rapid rate of growth in "know-how," which in turn leads to better processes and products. This theory suggests that technical change originates within the firm's R&D department and is not focused in its initial phase on fulfilling the specific needs of any specific potential client. Rather, new technologies result from a better understanding of more basic technological knowledge. Kamien and Schwartz (1982) suggest that the technology-push hypothesis has two broad implications: (1) Firms with larger R&D facilities are better able to exploit potentially feasible research projects than firms with smaller research departments; and (2) the general rate of increase in the scientific base has a direct effect on the rate of technological change. Kamien and Schwartz go on to suggest that technology-push and demand-pull are not competing hypotheses, but rather examine different sides of the bigger innovation picture. Technology-push can be seen as a long-run theory and demand-pull as a short-run theory. At present the conventional wisdom appears to be that demand-pull is more important to overall technological change than is technology-push.[4]

The somewhat simplistic view of technological change under neoclassical theory has come under attack in recent years. It has been suggested that neoclassical theory's emphasis on profit maximization is satisfactory at predicting macroeconomic technical change but does not adequately address how technological change occurs at the microeconomic level. In other words, neoclassical theory is unable to reconcile aggregate economy-wide technical change with firm-specific technical change. Evolutionary theory, mainly due to Richard Nelson and Sidney Winter, attempts to reconcile the problems posed by neoclassical theory (see Nelson and Winter, 1982). Evolutionary theory suggests that producers of products and developers of processes follow a set of routines in their efforts to improve existing products and processes. Such pursuit is said to lead to innovations. According to Nelson (1987) "...by an evolutionary theory we mean to include a relatively large class of models of change, with evolutionary theory in biology being a special case, and evolutionary theory of technical change being another special case.... Our theory (evolutionary) might be regarded as a special case of analysis of cultural evolution, where market values play an essential role and profit is the figure of merit, and where competitive pressures work to cut back unprofitable entities and augment profitable ones."

In summary, the neoclassical assertion that profits motivate technical change has generally been found to be true, though it does not explain all technical change--for example, serendipity. The more recent evolutionary theory attempts to address these shortcomings by adopting a more interdisciplinary approach. Unfortunately, while this new theory presents a more accurate representation of the real world, it also presents complicated hypotheses that are often difficult to test empirically because of data

[4] Note that technology-push and demand-pull technology change are not "water-tight" compartments. A technical change can result from both demand-pull and technology-push.

limitations. Although the new approach is promising, it is still being developed and has, thus far, not provided answers that are commonly accepted.

3.3 DIFFUSION

Stoneman (1986) defines diffusion as "the process by which innovations (be they new products, new processes, or new management methods) spread within and across firms." The literature on diffusion for the most part attempts to rationalize why a new technology that is superior to an old technology is not adopted immediately by all potential adopters.

Numerous factors, mostly based on common sense, have been suggested to affect the diffusion process. For example, Rosenberg (1976) mentions the following. First, new technologies take time to establish their superiority over existing technologies. This is, partly due to the fact that new technologies are not perfect when they are introduced and partly due to information about the new technologies that is not totally accurate or at a minimum not perceived to be accurate by potential adopters. Second, new technologies often require complex skills by the users, and such skills are developed over time. Third, the new technology may be complicated to manufacture or implement, requiring time for adaptations. Fourth, many new technologies cannot be implemented successfully unless required complementary products or processes are invented or improved. Fifth, improvements in old technologies may extend the lives of those technologies making the move to the new technology less attractive. Sixth, potential adopters may be dispersed geographically requiring increased marketing costs and also greater testing in areas of varying climates.

On a more formal level, several models of diffusion have been published which fit into two main schools of thought. One school of thought is based on Griliches' seminal 1957 paper; another is based on the work of Edwin Mansfield and his associates?
According to Griliches (1957), the relationship between the diffusion of a new technology and time plots like an "S" shaped or sigmoid curve, implying that the rate of diffusion increases at a diminishing rate eventually after initially increasing at an increasing rate.[6] Griliches arrived at his conclusions while studying the factors affecting the variance in the diffusion of hybrid corn in the United States. Griliches moved the notion of technological diffusion from something not explained very well within the neoclassical framework to a process that could be shown to obey forces based on profit maximization. According to

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[5]It is interesting to note that early works on technological change, such as Schumpeter's (1947) seminal piece, did not explicitly outline the forces affecting diffusion. Schumpeter's reasoning of the diffusion process was that potential profitability leads someone to innovate, and this profitability from the new technology induces other firms to imitate, thus resulting in diffusion.

[6]Note that a "S" shaped curve can take on various mathematical forms. The logistic and lognormal curves are commonly used.

Griliches, "the 'process of adopting and distributing a particular invention to different markets and its acceptance by entrepreneurs, is amenable to economic analysis. It is possible to account for a large share of the spatial and chronological differences in the use of hybrid corn with the help of "economic" variables. The lag in the development of adaptable hybrids for particular areas and the lag in the entry of seed producers into these areas can be explained on the basis of varying profitability of entry. Also, differences in both the long-run equilibrium use of hybrids and the rate of approach to that equilibrium level are explainable, at least in part, by differences in the profitability of the shift from open pollinated to hybrid varieties."

Although Griliches' approach was a step in the right direction, it simply asserted that diffusion follows an "S" shaped curve and ignored the basic question of why that pattern is typically followed. It also ignored such questions as (1) will different innovations have different diffusion curves, and (2) what specific characteristics of the technology and the sectors adopting and disseminating the technology--other than profitability--are important in determining the specific diffusion path?

In an attempt to address why diffusion follows a "S" shaped curve, Mansfield, in his 1968 book, put forth the idea of epidemic theory. Basically, Mansfield asserted that the process of technological diffusion can be likened to medical epidemics, which, given special characteristics, can be shown conceptually to generate a "S" shaped curve. In other words, diffusion occurs over time as more and more firms come in contact with those who have already adopted a new technology. A somewhat similar approach, known as the Bayesian approach, has been advocated by Stoneman (1983). According to this theory, firms learn in a Bayesian[7] way from their experience. Over time firms learn about the characteristics of the new technology, which alters the desired level of use. Both Mansfield's and Stoneman's approaches are based on the notion that information, cost of adoption, and uncertainty are keys to why firms do not immediately switch to a new technology. Information spreads like an epidemic and reduces the associated uncertainty, thus increasing the acceptability of the new technology to potential adopters.

Numerous papers have extended the basic arguments discussed above to include additional economic variables and to test specific hypotheses. For example, Reinganum (1981) modeled diffusion among firms as an oligolopy game in which firms maximize the present discounted value of future profits by undertaking strategic behavior.8 Reinganum

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[7]Bayesian updating is where the decision-makers use their past experience to change their judgements about substitutes. These changes, such as the probability that a new product replaces an old, may alter their future actions.

[8]Oligopoly is a type of market structure between the extremes of competition and monopoly. In competition no single firm is large enough to have an impact on market prices. In monopoly one firm controls the entire market. In an oligopoly, there are a few interdependent firms who either collectively or individually set the industry price. The firms within that market play strategic games which may determine market prices, or in the case of Reinganum (1981) determine the time path of diffusion.

suggests that potential profits to be gained from adopting a new technology decline as the number of firms that have already adopted the technology increases, leading to the typical diffusion time path. Jensen (1982) developed a conceptual model of diffusion to show that firms may delay adoption of an invention if there is uncertainty with respect to the profitability of the new technology. Hannan and McDowell (1987) examined the adoption of automatic teller machines by U.S. banks and found that more concentrated banking markets reacted more strongly to rival adoption than banks in less concentrated markets. Other authors, such as Easingwood (1988), have attempted to monitor the diffusion of different new technologies. Easingwood developed seven classes of diffusion rates and found that the time required to achieve 75% market penetration ranges form 3.5 years to 28.4 years.

Economists have made progress in the study of technological diffusion in the past three decades. Unfortunately, due to the number of dynamic factors affecting diffusion, economists have not been able to develop a simple formula or set of formulae to explain technology diffusion. Factors such as market structure, business cycles, adoption costs, expectations, and so forth are changing constantly. A given new technology has to be evaluated by taking all of these factors into account. And not only do the relevant factors have to be identified, those factors must also be quantified. In the words of Stoneman (1986), "Different innovations in different industries will have different diffusion patterns (agriculture is not like aircraft); public corporation may behave different from private firms; and the regulatory environment may also affect the diffusion process."

Economists have, however, drawn some general conclusions from a more aggregate perspective. For example, Kamien and Schwartz (1982) have stated that while "There are few studies of the relationship between market structure and rate of diffusion of innovation,... they all appear to indicate that the rate of process innovation diffusion is positively related to the competitiveness of the industry into which it is introduced." Mansfield (1968) argued that the number of adopters of a new technology is a function of the adoption risk, the expected profitability of the acquisition, and the number of potential adopters. Greater adoption risk is generally recognized to slow the diffusion process, as do lower potential profitability and a greater number of potential adopters. Other factors found to influence diffusion rates include absolute capital requirements, the durability of the adopting industry's capital stock, the industry's rate of sales growth, the complexity of the new technology, the cost of information dissemination, and the stage of the overall business cycle.

3.4 POLICY ISSUES RAISED BY ECONOMISTS WITH RESPECT TO TECHNOLOGICAL CHANGE

The major policy issue raised by economists with respect to technological change has to do with the relationship between market structure and inventive, innovative, and diffusion activities. Given that policy makers desire optimal technical advances and can directly and indirectly adopt policies that impact on the structure of markets, the relationship between market structure and technological advance is of crucial importance to an overall technology-policy.

The relationship was first postulated by Schumpeter (1947) when he suggested that concentrated industries are more suited for rapid technical change. It was suggested that monopolies are better able to bear the risks of research and development and have the resources to move new technologies to market or create new markets. As stated above, although numerous economic assessments on the subject have been completed, a consensus opinion on the validity of Schumpeter's hypothesis has not been reached.'

Market structure involves various parameters, but most often refers to the number of firms and the power of those firms in the market." For example, in a bilateral monopoly market, a single buyer faces a single seller. In a purely competitive market no one producer or consumer is large enough to exert any control on market prices. A number of market structures exist between these two extremes and are referred to as oligopolies. Within an oligopolistic structure, producers with equal or varying market power take actions as if in a game to maximize some objective. Strategic maneuvers can also take place among producers and consumers. A common oligopolistic structure used in the conceptual literature is the Stackelberg structure in which the market consists of one dominant producer and many fringe firms that exert no market control individually.

Economists generally recognize that the relationship between market structure and technological change is nonlinear and goes in both directions.[11] For example, too much. competition for a new product or process may induce premature introduction, while a, monopolist may delay the introduction of its new technology [Barzel (1968)]. With regard to the effect of technological change on market structure, arguments fall into two main schools of thought. One school maintains that innovations create entry barriers by making it harder for potential entrants to raise finances for research and development. Incumbent firms are also said to have an advantage in terms of having established research facilities and investments in human capital. This effect is reinforced by learning by doing, or the improvement in efficiency gained with experience (see Levin, 1978). The other school of thought is of the view that innovations promote competition by enabling small firms to attack established markets through new products [see Kamien and Schwartz (1975, 1982) for literature reviews]. In reality, innovations serve both functions. The extent of influence of innovations on market structure has been shown to depend on,

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'See, for example, Kamien and Schwartz (1975 and 1982), Nelson and Winter (1978), Loury (1979), Futia (1980), Lee and Wilde (1980), Dasgupta and Stiglitz (1980a,b), Tandon (1984), Reinganum (1985), Dorfman (1987), and Goel (1987).

"'For measures of composition of markets, such as concentration ratios and Mirfindahl indices, see, for example, Scherer (1980). Other market structure parameters include vertical and horizontal integration, which in the case of vertical integration indicates the degree to which firms are involved with various production steps in the production of a product and in the case of horizontal integration indicates the involvement of the firms in other markets.

'See, for example, Goel (1987), Reinganum (1985), Dasgupta and Stiglitz (1980a,b), Lee and Wilde (1980), and Loury (1979).

among other things, the type of innovation, the type of market, and timing of introduction. For example, Lunn (1986) found that process and product innovations have different effects in terms of industrial concentration. Specifically, Lunn's conclusions are (1) there is a positive relation between concentration and process patenting, while the same is not true for product patenting; and (2) there is a weak positive link between advertising and product patenting.

Numerous studies and differing conclusions also exist with respect to the impact of market structure on technological change. For example and on the one hand, Angelmar (1985) found in a cross-sectional study of 160 business units that concentration had a negligible impact on research investment. On the other hand, Levin and Reiss (1984) empirically tested the Schumpeterian hypothesis for 2 and 3 digit SIC industries in the United States and found support for a direct relationship between research and development and market structure. However, problems with data aggregation have been argued to limit the confidence in the findings of Levin and Reiss. Further, Mansfield (1981) found in a study of 108 firms that more concentrated industries tend to have more interfirm variation in R&D than less concentrated firms. Dorfman (1987) studied the relationship between market structure and innovations in the computer and semiconductor industries. Her somewhat vague conclusions may represent the current state of the economics literature on the subject. Dorfman states that "It is evident, empirically, that at any given time there may be significant opportunities for innovation of the sort that small, new firms can exploit in markets that they can enter with the expectation of earning a satisfactory return on investment. At the same time there will remain opportunities for innovation that can only be exploited by large firms in protected markets."

3.5 MEASUREMENT ISSUES

A major reason for the ambiguity in economic research on technical change is the lack of good data. Data on research and development are scarce and imprecise. Firms are often unwilling to divulge information about their investments in R&D because such data are proprietary. And even if firms reveal their research expenditures, the measurement of research inputs is not simple. For example, research inputs (including human and non-human inputs) may be used for production purposes and vice versa. Another vexing problem is the measurement of human capital.

In efforts to obtain data on the outputs of research projects, economists have used the number of patents issued as a proxy measure. Unfortunately, this measure is not free of shortcomings. For example, it does not take into account the innovative activity that goes unpatented. Further there is no good way to weigh patents of varying importance. Comanor and Scherer (1969) used three different measures of technical change--number of patents, employment of R&D personnel, and value of new product sales. The authors found statistically significant positive relationships between patents and the other two measures of technical change. Hall et al. (1986) and Griliches et al. (1987) showed strong contemporaneous relationships between R&D and patenting.[12]

Another approach to the measurement of productivity of research has been the inclusion of R&D as a separate input in the firm's production process. See, for example, Lucas (1967) and Rasmussen (1973). However, the issue of appropriation of resources between research and other inputs plagues this approach.

3.6 CONCLUSIONS

Economists have been less than totally successful in studying invention, innovation, and diffusion either conceptually or empirically. The profession has moved from a position in which the notion of technological change did not fit very well within the profit-maximization neoclassical framework, to a position where profit maximization is recognized as a crucial part of the process--but only a part. Economists now generally recognize that technological change is a complicated process that requires interdisciplinary approaches. While on an aggregated basis, some understanding of the phenomenon and in fact predictive powers can be obtained from simple rules such as profit maximization, the problem is much more difficult to address at the firm and individual market levels. The contributions of the economics literature to a better understanding of technological change are therefore most evident when addressing the "big picture". Economists have not been particularly successful in understanding or predicting the "hows" and "whys" a particular technology is developed or diffuses within a particular market. This may change as better R&D data become available.

[12]For more on patenting, see Scherer (1984).

4. THE PUBLIC-PRIVATE INTERFACE

4.1 INTRODUCTION

This section moves away from the "big picture" concerning technical change and focuses on the more narrow topic of how the public sector and the private sector interact in the pursuit of technical change. A necessary precursor to this discussion is an explanation of why the public sector should be involved in the first place. Although most disciplines accept the need for government involvement in the process as a given, economists generally agree that the appropriate interaction between the two sectors must be built on an understanding of the problems that call for public sector involvement.

4.2 THE NOTION OF MARKET FAILURES

Much of economic theory is devoted to identifying a market structure in which producers and consumers interact in a way such that the allocation of resources is most efficient. The theory goes on to show that if the distribution of factor ownership is "correct", a free-market economy can maximize the social welfare. Unfortunately, the conditions under which such an outcome holds are somewhat restrictive. If certain conditions do not hold, economic theory suggests that the market allocation of resources will neither be most efficient nor welfare maximizing. These conditions are generally referred to as market failures and, in general, call for some form of public sector intervention [see, for example, Hirshleifer (1982), or Stiglitz (1988) for details].

Although an explanation of the theory and specific market failures is beyond the scope of this report, a general discussion of market failures helps to suggest why economists call for particular types of public sector involvement. There are three types of market failures that may result in the private sector's push for technical advance to be something less than the social optimum--(l) the lack of competitive markets, (2) the existence of market externalities, and (3) the lack of contingent commodity markets or failures with respect to information and uncertainty. While these market failures will be discussed in the following subsections on specific policies, a brief discussion of these failures at this point outlines the general types of public intervention called for by economists.

The lack of competitive markets refers to situations in which some of the producers and/or the consumers of a good or service have market power. In other words, some producers and/or consumers are large enough relative to the size of the market to have an influence on the market price. Factors other than size can also lead to market power. In general, the economics literature suggests that the fewer the competitors in a market the more severe the problems of resource allocation and social optima become. This general conclusion does not, however, apply necessarily to the notion of technical change. As discussed in the previous section, the Schumpeter hypothesis states that bigness promotes' 'rapid technical change. And although no consensus has yet been reached concerning the Schumpeter hypothesis, technical change may be a case in which a generally recognized market failure, may in fact give results superior to pure competition.

Economists do not, at this time, agree about the effects of a lack of competitive markets on technical change and therefore do not agree on public policies that directly or indirectly impact on market structure. It may be the case that bigness and fewness promote technical change by overcoming some of the other generally recognized market failures. In that case, movements away from competitive markets may be encouraged on the grounds of promoting technical change. (Other policy controls could be implemented to avoid other problems associated with less than perfectly competitive markets.) The verdict with respect to this market failure and public policies in response to that failure awaits future conceptual and empirical research.

Externalities refer to costs or benefits that result from the production and/or use of a good or service and which are incurred by individuals or firms that are not directly involved in the economic transaction regarding that good or service. Externalities occur because of ill-defined property rights. An example of an external cost is air pollution that results from a manufacturing process and is incurred by individuals that in no way use or benefit from the product being made. An example of an external benefit is when a process innovation of one firm helps another firm reduce its costs. When externalities exist, the price of the good or service does not reflect its true benefits and costs. Government intervention is sometimes suggested to correct the prices of the goods or services to reflect the externalities and to impose costs and benefits on the appropriate parties.

With respect to technological innovations, the externality of most concern is the developing firm's or the inventor's property rights to the innovation. If other firms can easily copy or directly use the innovation, an externality will exist, and the innovator will have less incentive to conduct research and development. Potential inventors are reluctant to invest heavily in research when they cannot reap the full rewards of their efforts. Specific public policy instruments to address problems of externalities are discussed in the following subsection.

The third market failure of concern, failures with respect to information and uncertainty, is present to some extent in all markets. These types of failures are quite complicated. The basic argument is, however, that all producers and consumers must either have perfect information or, in the cases where perfect information does not exist, all producers and consumers must be able to insure against the risk associated with the lack of certain information. The failure to meet this condition is sometimes referred to as a lack of contingent claims markets.

In the case of technological innovations, it is obvious that perfect information does not exist. In the cases of some technological advances --for example, evolutionary developments in a particular technology or a straightforward application of an existing technology to a new application--the uncertainties are small and groups of individuals and sometimes firms can, in effect, jointly insure themselves against the risk that development and/or diffusion of the new technology will not be successful. However, in other cases the uncertainties of technological developments are so great or the potential payoffs from the new technologies are so uncertain that individuals and firms cannot insure themselves against the risks. Also, inherent uncertainties are not evident ex-ante in all cases. In the cases where the risks are great and the potential payoffs are large and far in the future, arguments can be made that the public sector should directly or indirectly subsidize the R&D.

4.3 PUBLIC POLICY RESPONSES TO MARKET FAILURES

The market failures that lead to the private sector's suboptimal research and development efforts and therefore to less than socially optimal levels of technical change can be made less severe by government intervention. In this section we discuss various direct and indirect public policy instruments that can be used to correct the market failures or compensate for the negative effects of the market failures. By indirect policy instruments we mean those public sector measures that alter the incentive" structure of the private sector with respect to technical change such that the pursuit of invention, innovation, and diffusion is made more attractive, By direct policy instruments we mean the direct involvement of the public sector in one or more of the three stages of technical change--invention, innovation, and diffusion.

4.3.1 Indirect Intervention

Several types of policy instruments have been suggested by economists to address the three market failures discussed in the previous section. Below we discuss six specific indirect instruments that have. been advocated and to some extent implemented by the U.S. in an attempt to foster technical change.[13]

4.3.1.1 Antitrust Policies

Although the Schumpeter hypothesis remains unproven when viewed from the perspective of the entire economics discipline, there are researchers that argue that the hypothesis is true or false. In reality, the Schumpeterian hypothesis may or may not hold depending on the type of innovation and the type of market being considered. If the hypothesis is accepted as true, an obvious policy implication is that strong antitrust policies--i.e., policies that promote industries with firms of smaller size and less market power--are not particularly good if rapid technical change is a goal. To foster technical change, some antitrust rules might be made less severe, or at minimum firms might be encouraged to collaborate in the area of technical change--e.g., joint ventures. Such collaboration could also occur through, for example, trade organizations or through multifirm centers set up to develop and jointly utilize new technologies. This type of interfirm interaction is now receiving more consideration as U.S. regulators are following the leads of countries such as Japan.

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[13]For details on the U.S.'s efforts to promote technical change, see Moore (1988).

If the Schumpeter hypothesis is, however, false, the obvious implication is that smaller firms and more competition should be encouraged. For example, some argue that monopolists may delay the commercialization of their inventive activities because they do not want to affect the profits from their current product. Bittlingmayer (1988) argues that if competitors are allowed to cross-license or enter pooling agreements, the patents on their common products can lead to powers enjoyed by classic cartels. The firms could specify price or royalty terms that replicate the effects of price-fixing agreements.

4.3.1.2 Patents

The inability of firms and individuals to protect the rewards of innovative activities from competitors can severely limit the overall incentives of R&D. The commonly used measure to protect property rights of inventors is the patent. Patents protect a new technology--one judged to be of a kind that can be used to produce a substantially improved product or process--by conferring a monopoly right for a limited time to the inventor. Although the optimal length of patents is a subject of continuing debate [see Tandon (1982)], the current length of patents in the U.S. is seventeen years. In other countries, for example the United Kingdom, the length can be as long as twenty years.[14]

The patent system as a means to protect property rights has been and continues to be the subject of debate. Patents are generally recognized as a means to guarantee a return to the inventor for his research efforts, and some [see, for example, Scherer (1980)] argue that the patent system encourages the disclosure of information about the new technology. There are, however, costs associated with patents, and arguments exist about the extent of their net benefits. From a social welfare perspective, the maximum benefits of a new technology are realized when information about that technology is available free of charge. However, the patenting system works opposite to this condition. The basic argument is that patents will encourage inventive activity, but may restrict the diffusion of that activity. Economists suggest that a limited-period patent is the best response to this problem, but, as stated above, argue about the appropriate length of patent protection.

Stoneman (1983) argues that "The conflict between encouraging invention and discouraging diffusion is perhaps best considered at an empirical level." Two relevant questions are posed. "First, has the patent system worked effectively as an incentive to invention? Second, has the existence of property rights in invention significantly affected the spread of new technology?" Stoneman reviews the relevant literature and suggests that the empirical evidence shows that patents possibly play only a minor role in stimulating invention and in most cases do not prevent imitation. Patents may not, therefore, slow down diffusion to any great extent. Stoneman goes on to argue that

[14]Some have argued that patents accomplish their purpose only if used in combination with sound antitrust policy. Many firms, for example, patent products just to keep their rivals from inventing earlier. Such products are often never commercialized. For evaluation of effectiveness of patents see Judd (1985) and Kamien and Tauman (1986).

monopoly power in the hands of the inventor can or will slow down the use of new technologies to some degree.

Other economists have noted that other mechanisms exist for inventors to protect their innovations. For example, Arrow (1962) suggests that secrecy is an alternative way to maintain property rights to an invention, as may be brand loyalty, or other significant entry barriers. Mcgee (1968) suggests that patents may provide relatively too much of some kinds of research, and too little of others. Since not all discovery is patentable, the law may tend to bias search toward areas that are favored by it.

The consensus opinion about patents would appear to be that patents perform an essential function; but our current failure to adequately measure their performance and to monitor the incentives of the patent holders makes them a less than perfect instrument to protect inventive and intellectual property rights.

4.3.1.3 Standardization

Recall that the third type of market failure mentioned in the above subsection had to do with the lack of information about new technologies and the risk that lack of information imposes on firms. The uncertainties are usually divided into two categories--technological and market. Government regulations to promote standardization of products and processes has been suggested to help reduce technological uncertainty by increasing the likelihood that a new technology will mesh with other existing technologies. It is argued that standardization, if left to a firm or group of firms, can be misused by making standards too complex for rivals to maintain. Essentially, complex standards can create unfair barriers to entry and result in problems associated with non-competitive markets.

4.3.1.4 Provision of Information

Consumers are often apprehensive about new technologies, resulting in market uncertainties. Government provision of information about new technologies is often called for, especially in cases where positive externalities may result from the diffusion of the technology. The government's activities in promoting energy conservation technologies--where positive externalities may exist from reducing oil consumption--are an example. Further, if information is of a non-proprietary type, it may be more efficient for the government to disseminate it. Another example is the activities carried out by the National Institute of Standards and Technology (NISI'). The testing of inventions, such as those conducted at NIST and the national labs, provide information about the technical aspects of new technologies and may be all that is needed to gain acceptance by the public."

[15]Producers in the innovation process face a different set of uncertainties such as risks associated with rival inventions and uncertainty about success in-research.

The public sector may also play an important role in providing information that reduces market uncertainties. Summary market information provided by government agencies such as the Department of Commerce and the Department of Energy and by national laboratories may only be available from public records: Provision of such information by the private may not be possible because the data on which the summary statistics are based are often proprietary and thus would be difficult or impossible to collect by an outside organization.

4.3.1.5 Government Procurement

The public sector can also decrease the market uncertainties associated with a new technology by insuring a buyer for the technology or the product or service from the technology. It has been shown that the ability of the government to influence the innovative process is inversely related to the number of potential buyers of the new technology. It has also been shown empirically that government procurement policies have led to breakthroughs in certain new technologies such as the computer and aircraft industries. [See, for example, Dorfman (1987) and Gansler (1984)].

4.3.1.6 Taxes and Subsidies

Taxes and subsidies can be used as a means to reduce externalities by forcing free-riders (firms or individuals that benefit from a new technology without paying the inventor for the privilege to use the technology) to pay for external benefits. Alternatively, taxes and subsidies can be used as a method to override the effects of market failures, rather than correcting them. The government can provide general incentives to industry to increase their inventive activities through, for example, tax credits on R&D efforts. Or government can provide subsidies to specific firms to develop/adopt specific technologies. Such projects include R&D that would not otherwise be carried out by private firms due to their risky nature, high capital requirements, or long gestation periods; or they may be projects of great national or strategic importance. A problem with such sponsorship is that the public sector cannot determine the extent of benefits or spillovers to the contractor and is unable to charge for such benefits. Additionally, the government cannot monitor the intensity of research effort.

Government can also award diffusion grants to inventors. Such grants could provide the resources that inventors need to launch their inventions. Adoption grants to potential consumers are another way by which new products with high adoption costs can be easily adopted. For example, if a new technology involves the switch from labor intensive production techniques to capital intensive ones, high initial capital requirements may delay adoption.

An example of a current government program to promote selected technologies is the U.S. Department of Energy's Energy Related Inventions Program (ERIP). That program supports the development and transfer of selected new energy technologies and thus helps to overcome market failures associated with externalities and with information and uncertainty. It can be argued, in fact, that the public-sector recognition given to the new technologies is as valuable as direct government funding. The government's adoption of a technology effort signals to the private sector the public sector's belief that the new technology has technical and/or commercial merit. That provision of information may in turn promote private-sector financial support.

4.3.2 Direct Intervention

An alternative to the government eliminating or counteracting market failures that hinder the private sector's inventive activities is to have the public sector participate directly in technical change. Participation can occur at the inventive, innovative, and/or diffusion steps.

Various reasons may exist for direct government involvement. For example, it is often difficult for government to identify potential inventors that could conduct R&D of certain types. In addition, the lack of a means to adequately monitor the research process creates what economists call a "principal-agent" problem. The government, as the principal, is unable to monitor the activities of its agent--the contractor. On the one hand, there are measurement problems dealing with appropriability and the value of R&D activities. On the other hand, there is a lack of an adequate measure of success in innovation. For example, in most cases there may be only one firm that is able to successfully invent a new technology, but those who fail to achieve the invention may still have improved their ability to pursue subsequent research projects. The quantification of such gains is difficult, if not impossible. Thus, the inability to monitor the agent's behavior leads to one argument for direct government involvement in technological change.

Further, in the case of long-term, high-risk R&D the public sector may hold a relative advantage because of the continuity of effort and economies of scale. In addition, there is an obvious role for government to play in the research, development, and use of innovations that are public goods, such as military technologies. In this subsection we review the ways the public sector can be directly involved in technological change. We also explore the various ways and points at which an interface between the public and private sectors can occur.

4.3.2.1 Points at which the Public-Private Interface Can Occur

Figure 1 summarizes the various points at which the public and private sectors can interface in the process of technical change. The three steps in technical change are given--invention, innovation, and diffusion--along with three general avenues of technical change--public sector, private sector, and public-private sector joint ventures. Note that there are several nodes at which this interface or transfer of ideas and technologies can occur--ranging from an interface at the invention step through joint ventures to an interface at the diffusion step. At one extreme the government may simply be involved in the generation of ideas--through public-sector invention at, for example, national laboratories or through joint ventures with private firms--and then transfer those ideas to the private sector for the innovative and diffusion step. At the other extreme the government may through joint ventures or on its own be involved in the inventive,

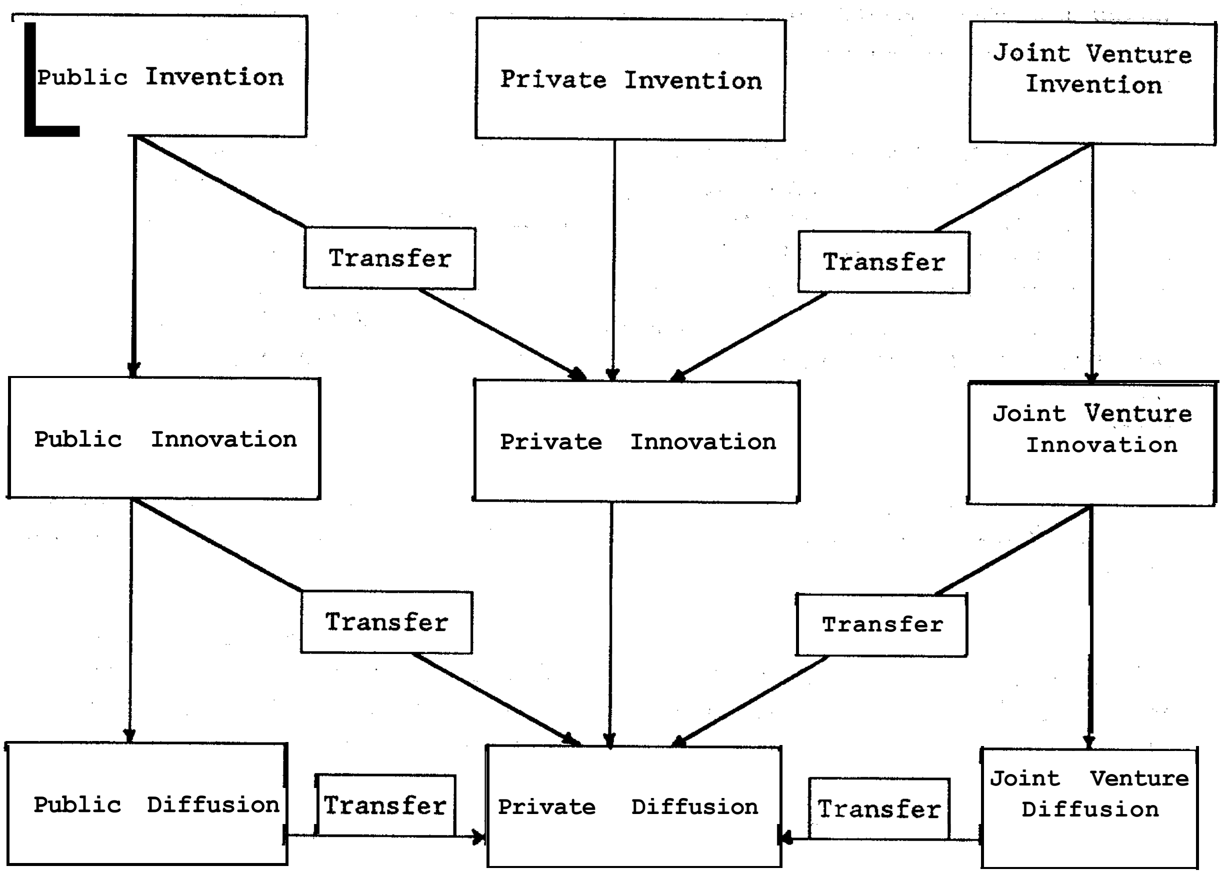

Fig. 1. Points at which the public-private interface can occur

innovative, and diffusion steps. Transfer to the private sector may, in fact, never occur in this latter extreme.

Several questions present themselves when the public-private interface is viewed as in Fig. 1. For example, can we say anything about what types of technologies are best transferred at different points? What transfer mechanisms work best at different transfer points and for different types of technologies? What policy options are available at the different potential transfer points? Is there any way to measure the effectiveness of transferring technologies at different points? How much government involvement is optimal?

For the most part, the economics discipline has not addressed questions at this level of disaggregation. As discussed in previous sections of this report, the economics profession has focused on the big picture and paid little attention to prescribing how a public-private interface should be structured given a particular technology and particular market conditions.

In the following subsection we present some general comments with respect to the direct involvement of the public sector in the innovative process., While the current literature is limited, a review of that literature suggests potential relationships and fruitful avenues for future research.

4.3.2.2 Public-Private Sector Joint Ventures

An interface can be set up between the public and private sectors at any of the three technical change stages. Economists have argued that the advantages of joint-venture R&D include the ability to pool resources, while the major drawbacks are in reaching some kind of an agreement on sharing post-invention rewards and identification of compatible potential partners.

Although much of the work by economists in the area of joint ventures has concerned joint ventures among private firms, some of that research is suggestive of public-private sector joint ventures. Jacquemin (1988) suggests several benefits of joint ventures. Those benefits include the following: (1) Cooperative agreements are an alternative to either pure market transactions or integration within a firm under a centralized administrative structure. In-house development or mergers are said to create inflexible structures without easy means for switching research capability, strategy, and partners over time. Further, arm's-length transactions do not allow for long-term relationships, which are generally crucial in technology, (2) The second advantage of cooperative R&D is to increase the speed of invention and innovation with diminished risk of failure; and (3) The pooling of various complementary resources in R&D can provide financial capital at better conditions, spread the fixed and generally sunk costs of technology development, and produce synergistic effects by the combination of research information, teams of scientists, technical and marketing know how, and so forth. Jacquemin lists the drawbacks of joint ventures as (1) the difficulty involved in selecting partners and the possibility of defining contributions by the participants, and (2) the difficulty in managing joint ventures and, sharing the benefits of those ventures.

The main argument in favor of encouraging joint ventures concerns the difficulty in appropriating the returns to inventive activities.[16] Joint venture R&D can be seen as a way to simultaneously internalize the externalities caused by significant R&D spillovers, hence improving the incentives and limiting wasteful duplication. The joint venture is also argued to provide more efficient sharing of information between the public and private sectors and among private sector firms. Katz (1986) has argued unambiguously that cooperative R&D increases both R&D and production with respect to the non-cooperative solution.[17]

4.3.2.3 Public Sector Invention. Innovation, and Diffusion

The government can directly engage in invention, innovation, and diffusion by setting up research facilities such as the national laboratories or by sponsoring activities at public sector facilities such as the Tennessee Valley Authority. Benefits of these activities include the ability of government to fund ambitious and unique (e.g., in the sense of special defense needs) research projects and the capability to bear adverse consequences of uncertain research. Additionally, government is most suited to invest in generic research because generic knowledge is usually nonproprietary. Government can aid in development by validating and testing technologies invented by private inventors at its laboratories. Government assistance in diffusion can come in the form of marketing through government facilities, e.g., the National Energy Software Center. A single government unit may engage in all three stages of the innovative process.

The drawbacks of independent government research activities include possible inefficiencies due to the lack of market pressures and due to bureaucratic "red tape." Nelson (1987) also argues that due to the absence of perfect information, government participation in R&D may replace or duplicate private research efforts. Empirical evidence on this issue remains elusive, as do conclusions regarding the impact of government R&D on private-sector inventive efforts.[18] One reason for the lack of research on direct government participation in R&D is that the government often invests in defense-related R&D whose findings are seldom made public.

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[16] Economists have devoted considerable efforts to. the problem of non-appropriability of R&D gains. See, for example, Dasgupta (1987) for a literature survey. Also see, Dasgupta and Stoneman (1987).

[17] For more on research joint-ventures, see Grossman and Shapiro (1985).

[18] See, for example, Lichtenberg (1987) for more details.

5. CONCLUSIONS

The role of the federal government in the innovative process remains the subject of significant debate among economists. Although most economists would agree that some role must be played by the public sector, our current conceptual and empirical knowledge is lacking. Little consensus has thus been reached about how the government should respond to the problem in general, and even less consensus exists about how particular technologies in particular markets should be dealt with. Dasgupta (1987) states that "The economics of technology policy is in its infancy.... It is widely appreciated today that R&D investment has a strong influence on an economy's performance. It is also appreciated that information, the output of R&D, possesses exceptional characteristics. Furthermore, we have seen that R&D technologies possess features which make the activity of information production particularly problematic. And yet the massive recent literature on public economics has barely touched upon these matters. The microeconomic theory of technology policy...is somewhat of a stepchild of our profession."

This paper has presented a general overview of the economics literature on technological change and focused particularly on the interface that exists between the public and private sectors in promoting the transfer and diffusion of new technologies. The paper has suggested that the public sector can encourage the process of innovation by either directly participating in the process of technical change or by indirectly stimulating the private sector's innovative activities. And although both methods have been shown to promote technical change, economists have not yet been able to develop a generally agreed upon formula that dictates what method is most appropriate in any given case. Nelson's (1987) views on public sector participation in the R&D process may best summarize the state of the economics literature with regard to the question of public involvement: "One can see the task of institutional design as somehow to get the best of both worlds. Establish and preserve property rights, at least to some degree, where profit incentives are effective in stimulating action, and where the costs of keeping knowledge private are not high. Share knowledge where it is efficient to do so, and the cost in terms of diminished incentives is small. Do the work cooperatively, or fund it publicly, and make public those aspects of technology where the advantages of open access are greatest, or where proprietary claims are difficult to police."

It is likely that the arguments by economist with respect to the government's role in technological change will become more definitive as more detailed conceptual and empirical studies are undertaken. It is unlikely, however, due to the number of dynamic factors that are known to influence the innovative process, that the economics profession will develop a formula or set of formulae for technical change or the involvement of the public sector in that change. A movement toward interdisciplinary research, which is currently underway, is the most promising avenue for studying the role of public policy in promoting technical change.

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