Microeconomic Policy and Technological Change

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My assigned topic is the question: Can policymakers spur or deter technological change? The question is to be addressed from a micro perspective, by examining policies regarding research and development (R&D), patents, and competition. Since there is no point in keeping the reader in suspense, I shall argue that government policy plays a major role in influencing the rate of technological change in many important industries.

The paper begins by looking at the salient features of federal support of R&D activities in the private sector of the economy. The next two sections take up the rationale for federal support of R&D and then consider whether, on a priori grounds, it is possible to say with any reasonable degree of certainty that underinvestment in R&D occurs in particular parts of the private sector.

Measures of the social benefits from new technology are then taken up, with particular emphasis on the social rate of return from investments in new technology. The gap between social and private rates of return from investments in new technology is also discussed. Building on the previous results, I then put forth five guidelines regarding public policy toward civilian technology. These guidelines are not new, but I believe that they are just as applicable today as they were when first presented 20 years ago. The final sections of the paper take up the patent system and antitrust policy, two areas continually subject to attention and controversy.

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Federal Support for R&D

Expenditures in the United States for R&D in 1995 totaled $171 billion, of which about 35 percent was financed by the federal government (National Science Foundation 1995b). Federal R&D expenditures are concentrated heavily in a relatively few areas. In 1996, almost $38 billion was spent on defense R&D and almost $8 billion on space R&D. Health R&D accounted for over $11 billion. Other areas with significant amounts of federally financed R&D were energy, environmental protection, transportation, agriculture, and education. The federal government also spent a considerable amount on the general advancement of science and technology (National Science Foundation 1995a).

Much of the federal R&D takes place outside government laboratories. In 1995, the Department of Defense performed about one-fourth of its R&D in government laboratories; most of the remainder was carried out by industrial firms. Similarly, NASA did about one-quarter of its R&D in government laboratories, while industry performed much of the rest. On the other hand, the Department of Energy undertook about one-half of its R&D in federally funded centers like Oak Ridge, Sandia, Brookhaven, and Los Alamos, some of which are administered by private firms, some by universities and other nonprofit institutions. Still other agencies, like the Department of Agriculture and the Department of Commerce, carried out most of their R&D in their own laboratories.

Industries also exhibit substantial differences in the extent to which their R&D is financed by the federal government. As shown in Table 1, in 1992 the federal government financed about 40 percent of the R&D in transportation and computer programming, the industries with the largest shares of federally financed R&D. In the chemical, petroleum, primary metals, and food industries, among others, the percentage of total R&D that is federally financed is much smaller.

Finally, our nation's colleges and universities are heavily dependent upon the federal government for R&D funds. About 60 percent of the R&D carried out by the colleges and universities is financed by the federal government. Table 2 lists the 30 universities that received the most federal support for R&D in 1993 and the amount each received. As would be expected, the leading research-oriented universities, such as MIT, Harvard, Cornell, Michigan, and Stanford, ranked among the highest. In 1990, the 100 universities and colleges at the top of this list received about 85 percent of the total federal obligations to colleges and universities.

Rationale for Federal Support of R&D

The rationale for federal support of R&D varies from one area to another. Many areas with relatively large amounts of federally financed R&D are intended to provide new or improved technology for public

Table 1
Funds for R&D Performance, by Industry and Source, 1992
Millions of Dollars

Industry	Industry Financed	Federally Financed	Total
Total	96,654	24,660	121,314
Food	1,371	0	1,371
Tobacco	40	0	40
Textiles	190	[a]	[a]
Apparel	69	[a]	[a]
Lumber	[a]	0	[a]
Furniture	168	[a]	[a]
Paper	1,191	[a]	[a]
Printing	[a]	[a]	290
Chemicals	16,420	[a]	16,711
Petroleum	2,330	9	2,339
Rubber	1,337	[a]	[a]
Leather	[a]	0	[a]
Stone, Clay, and Glass	479	[a]	[a]
Primary Metals	542	[a]	555
Fabricated Metal Products	764	293	1,057
Machinery	14,073	1,062	15,135
Electrical Equipment	9,689	3,857	13,546
Transportation	15,726	10,738	26,484
Instruments	7,426	2,226	9,652
Miscellaneous Manufacturing	322	[a]	[a]
Communication Services	4,131	[a]	[a]
Electric and Gas	309	[a]	[a]
Computer Programming	3,889	2,774	6,663
Hospitals and Medical Laboratories	424	191	615
Research, Development, and Testing	8,286	1,381	9,667
Other Manufacturing	7,172	257	7,429

[a] Data withheld to avoid disclosing operations of individual companies.

Source: National Science Foundation, *Research and Development in Industry, 1992*. (Washington, DC: National Science Foundation, 1995.)

sector functions. Defense and space exploration, for example, are public goods; it is inefficient (and often impossible) to deny their benefits to a citizen who is unwilling to pay the price. The government is the sole or principal purchaser of the equipment used to produce such goods; and since it has primary responsibility for their production, it must also take primary responsibility for the promotion of technological change in relevant areas. Although much of the R&D of this type is performed by private firms, its primary objective is to promote technological change not in the private sector but in the public sector. While some beneficial spillover to private industry may occur, it is likely to be much less than if the funds were spent directly on private sector problems.

Table 2
Federally Financed R&D Expenditures in Science and Engineering at the 30 Colleges and Universities Receiving the Largest Amounts, 1993

Rank and University		Millions of Dollars	Rank and University		Millions of Dollars
1	Johns Hopkins	674	16	Penn State	160
2	Washington	269	17	California, Berkeley	156
3	MIT	267	18	Southern California	150
4	Stanford	254	19	Pittsburgh	142
5	Michigan	250	20	Illinois	141
6	California, San Diego	243	21	Texas	139
7	Wisconsin	214	22	Colorado	139
8	California, San Francisco	210	23	Duke	136
9	Cornell	195	24	North Carolina	131
10	California, Los Angeles	189	25	Rochester	131
11	Columbia	183	26	Washington (St. Louis)	129
12	Harvard	182	27	Texas A & M	123
13	Minnesota	175	28	Arizona	113
14	Pennsylvania	174	29	Ohio State	109
15	Yale	169	30	California, Davis	105

Source: National Science Foundation, *Academic Science and Engineering R&D Expenditures, Fiscal Year 1993*, NSF 95-332.

Another rationale for large federally financed R&D expenditures is the presence of some form of market failure. The fact that farms are relatively small productive units has been used to justify federally financed R&D for agriculture, for example. Further, some federally financed R&D is directed toward the general advance of science and technology. Such expenditures seem justified because the private sector will almost certainly invest less than is socially optimal in basic research. This underinvestment occurs because the results of such research are unpredictable and usually of little direct value to the firm supporting the research, although potentially of great value to society as a whole.[1]

ARE EXISTING FEDERAL PROGRAMS ADEQUATE?

Economic theory has been used to analyze whether existing federal programs supporting civilian technology are likely to be adequate. Because it is often difficult for firms to appropriate the benefits that society receives from new technology, private investors may tend to devote too few resources to its development. In particular, the more competition there is and the more basic the information, the less appro-

[1] See Alic, Branscomb, Brooks, Carter, and Epstein (1992); Cohen and Noll (1994); Eads (1974); Grossman and Helpman (1991); and Mansfield and Lee (forthcoming).

priable the new technology is likely to be. Also, firms may invest too little in inherently risky R&D efforts, because many seem to be risk averse and have only limited and imperfect ways to shift these risks.

Moreover, particular kinds of R&D may be characterized by economies of scale that prevent small organizations from undertaking them efficiently. This argument seems much more applicable to development than to research, however. While firms may have to be of a certain minimum scale to do many kinds of R&D effectively, this scale may be a relatively small share of the market. In fact, small firms have been responsible for many important innovations, while many big firms have concentrated on more minor product improvement innovations. Nonetheless, it is often argued that some industries are so fragmented, they cannot do the proper amount of R&D.

Despite the relevance of the preceding arguments, they by no means prove that there is at present any underinvestment in civilian technology. For one thing, these arguments generally assume that markets are perfectly competitive, whereas in fact many important markets are oligopolistic. In oligopolistic markets, many economists believe that firms often stress product improvement as a form of rivalry, rather than direct price competition. Because of tacit agreement among the firms, product improvement may even be the principal form of rivalry, with the result that more may be spent on R&D than is socially optimal. This is not, however, a proposition that is easy to prove or disprove.

Another reason why there may be no underinvestment in civilian technology is that the government is already intervening in a large number of ways to support civilian R&D. For example, a tax credit has been granted for R&D and the National Institute of Standards and Technology's Advanced Technology Program has awarded hundreds of millions of dollars in grants. Sematech (the Semiconductor Manufacturing Technology Corporation) has received federal subsidies of $100 million a year, and in industries like aircraft, a host of government influences promote R&D and technological change. It is not obvious, on a priori grounds, thus, that the government has not already offset whatever latent underinvestments existed in R&D.

Going a step further, Partha Dasgupta and Joseph Stiglitz (1980) have questioned whether on balance there is any reason for supposing that a market economy results in too low a level of investment in R&D. They conclude that the fact that only a relatively few firms are engaged in R&D does not show that a market economy contains too little R&D activity, and that the pressures of competition may result in excessive speed in research.[2]

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[2] See Arrow (1962); Cohen and Noll (1991); Dasgupta and Stiglitz (1980); Mansfield (1996), and Romer (1990).

Measuring Social Benefits from New Technology

Because pure theory cannot tell us whether underinvestment in R&D exists in the private sector (and if so, where it is most severe), let us turn to the available empirical studies of the returns from R&D of various types. Of course, measuring the social benefits from new technology presents a variety of problems. Any innovation, particularly a major one, has effects on many firms and industries, and obviously it is difficult to evaluate each one and sum them up properly. Nonetheless, economists have devised techniques that should provide at least rough estimates of the social rate of return from particular innovations, assuming that the innovations can be regarded as basically resource-saving in nature.

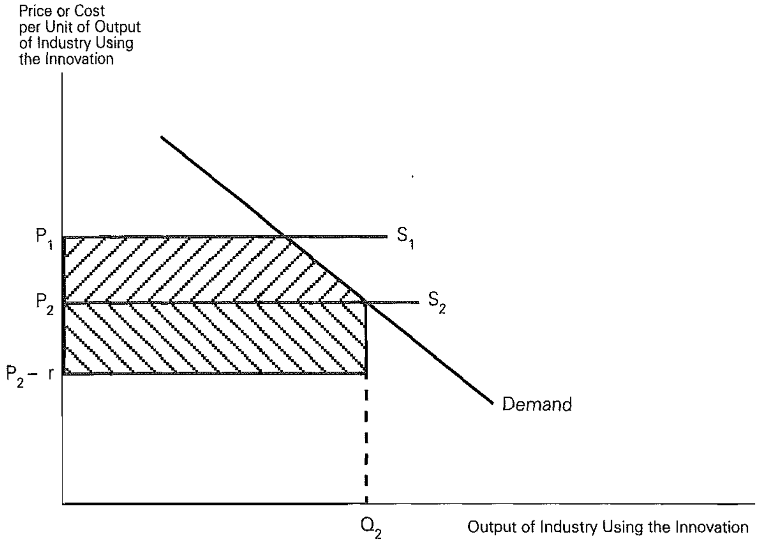
Consider a new product (used by firms) that can shift the supply curve of the industry using the new product. How far downward this supply curve will shift depends on the pricing policy of the innovator. Assume that the innovator decides to set a price for its new product that yields a profit to the innovator equal to r dollars per unit of output of the industry using the innovation (for example, r dollars per appliance, in the case of a new type of metal used by the appliance industry). Also, assume that the industry using the innovation is competitive, that its demand curve is as shown in Figure 1, and that its supply curve is horizontal in the relevant range. In particular, suppose that, before the advent of the innovation, this supply curve was S_1 in Figure 1, and the price charged by the industry using the innovation was P_1. After the advent of the innovation, this supply curve is S_2, and the price is P_2.

The social benefits from the innovation can be measured by the sum of the two shaded areas in Figure 1. The upper shaded area is the consumer surplus due to the lower price (P_2 rather than P_1) stemming from the use of the innovation. Also, a resource saving occurs, along with a corresponding gain in output elsewhere in the economy, because the resource costs of producing the good using the innovation—including the resource costs of producing the innovation—are less than P_2Q_2. Instead, they are P_2Q_2 minus the innovator's profits from the innovation, the latter being merely a transfer from the makers of the good using the innovation to the innovator. Thus, in addition to the consumer surplus arising from the price cut, a resource saving occurs, amounting to the innovator's profits.

In many cases, two adjustments must be made in this estimate, which corresponds with the lower shaded area in Figure 1. First, if the innovation replaces another product, the resource saving described in the previous paragraph does not equal the innovator's profits from the innovation, but these profits less those that would have been made (by the innovator or other firms) if the innovation had not taken place and the displaced product had been employed instead. This lesser amount is the proper measure of the resource saving. Second, if other firms imitate

Figure 1

Social Benefit from New Product



the innovator and begin selling the innovation to the industry that employs it, their profits from the sale of the innovation must be added to those of the innovator to get a complete measure of the extent of the resource saving caused by the innovation.

One also can measure the social benefits from new products used by individuals rather than firms, and from new processes. But since the principles involved are much the same as those described above, we will not present the measurement procedures here (see Mansfield et al. 1977a, 1977b).

Social Rates of Return

By a social rate of return, we mean the interest rate received by society as a whole from an investment. To economists, the social rate of return from investments in new technology is important, since it measures the payoff to society from these investments. A high social rate of return indicates that society's resources are being employed effectively and that more resources should be devoted to such investments, if the rate of return stays high. In a series of papers, I have tried to describe the many difficulties in measuring and interpreting the social rate of return.[3] They are numerous and important, but until something better comes along, estimates of this sort are likely to continue to be used.

Although earlier efforts to measure the social rates of return from such investments had been made in agriculture, the first attempt to measure the social rate of return from investments in industrial innovations was published in 1977. The innovations that were included in the study took place in a variety of industries, including primary metals, machine tools, industrial controls, construction, drilling, paper, thread, heating equipment, electronics, chemicals, and household cleaners. They occurred in firms of quite different sizes. Most of them were of average or routine importance, not major breakthroughs. While the sample could not be viewed as randomly chosen, we found no obvious sign that it was biased toward very profitable innovations (socially or privately) or relatively unprofitable ones. The findings indicated that the median social rate of return from the investment in these innovations was 56 percent, a very high figure (Mansfield et al. 1977a, 1977b).

It is important to recognize that this sample was not confined to "winners." We went to considerable trouble to get as representative a sample as possible. The innovations were chosen at random from those carried out recently by the cooperating firms. A very substantial number turned out to have low or negative private returns. (One interesting finding was that the social rate of return tended to be very high for these "losers" as well as for the "winners".) One of the contributions of this study, in our opinion, was that it included a broader and more representative sample than any in the past. To extend this sample and replicate the analysis, the National Science Foundation commissioned two studies, one by Robert R. Nathan Associates (1978) and one by Foster Associates (1978). Their results, like ours, indicate that the median social rate of return tends to be very high. Based on its sample of 20 innovations, Nathan Associates found the median social rate of return to be 70 percent. Foster Associates, based on its sample of 20 innovations, found the median social rate of return to be 99 percent.

More recently, Manuel Trajtenberg (1990) estimated that the social rate of return to R&D in the field of CT scanners in medical technology was about 270 percent. As he is careful to point out, the interpretation of the gains as social depends on the motives underlying the behavior of hospitals when choosing medical technologies. Also, as in the example of hybrid corn, which Zvi Griliches (1958) studied, a high rate of return

[3] For example, see Mansfield (1991a, 1991b, 1992, 1995d) and Nadiri (1993).

would be expected because the innovation was known in advance to be a gusher, not a dry hole. But bearing these things in mind, Trajtenberg's results certainly are consistent with the proposition that the social rate of return from investments in new technology tends to be high.

In sum, practically all of the studies carried out to date indicate that the average social rate of return from industrial R&D is very high. Moreover, the marginal social rate of return also seems high, generally in the neighborhood of 30 to 50 percent. As I have pointed out elsewhere, a variety of very important problems and limitations are inherent in each of these studies.[4] Certainly, they are very frail reeds on which to base policy conclusions. But recognizing this fact, it nonetheless is remarkable that so many independent studies, based on so many types of data, result in so consistent a set of conclusions.

The Relationship between Social and Private Returns

The gap between social and private rates of return from investments in new technology is of great importance. A major rationale for government support of civilian technology is that some R&D projects have social rates of return far in excess of their private rates of return. What determines the gap (if it exists) between the social and private rates of return? One relevant factor is the market structure of the innovator's industry. If the innovator is faced with a highly competitive environment, it is less likely to be able to appropriate a large proportion of the social benefits than if it has a secure monopoly position or is part of a tight oligopoly. Of course, the extent to which the innovator is subjected to competition, and how rapidly, may depend on whether the innovation is patented. Another consideration of at least equal importance is how expensive it is for potential competitors to "invent around" the innovator's patents, if they exist, and to obtain the equipment needed to begin producing the new product (or using the new process). In some cases, like Du Pont's nylon, it would have been extremely difficult to imitate the innovation (legally). In other cases, a potential competitor could obtain and begin producing a "me-too" product (or using a "me-too" process) at relatively little cost.

Another factor that economists have emphasized as a determinant of the size of the gap between social and private rates of return is whether the innovation is major or minor. According to R.C.O. Matthews (1973), the "degree of appropriability is likely to be less . . . in major innovations than in minor ones" since major innovations are more likely, in his view, to be imitated quickly. Similarly, on the basis of a model stressing the

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[4] For example, see Mansfield (1991b).

indivisibility of information, Kenneth Arrow (1962) concluded that "the inventor obtains the entire realized social benefit of moderately cost-reducing inventions but not of more radical inventions."

Still another consideration sometimes cited is whether the innovation is a new product or a new process. Thus, Matthews hypothesized that the degree of appropriability might be less for process innovations than for product innovations. On the other hand, Richard Nelson, Merton Peck, and Edward Kalachek (1967) stressed that new processes can often be kept secret and that it frequently is difficult for one firm to find out what processes another firm is using.[5] This idea, of course, suggests that the gap between social and private rates of return might be greater for products than for processes.

Although most of these hypotheses seem quite plausible, they unfortunately have been subjected to just one systematic empirical test, which was based on data for only about 20 innovations (Mansfield et al. 1977a, 1977b). The results seem to support the hypotheses that the gap between social and private rates of return tends to be greater for more important innovations and for innovations that can be imitated relatively cheaply by competitors. Apparently, when the cost of imitating the innovation is held constant, it makes little or no difference whether the innovation is patented—which seems reasonable, because whether or not a patent exists is of relevance largely (perhaps only) because of its effects on the costs of imitation. It is worth noting that this simple model can explain about two-thirds of the observed variation in this gap among the product innovations in our sample. However, at the same time, it is important to bear in mind the small size (and age) of the sample.

Public Policy toward Civilian Technology

For about 25 years, a number of economists have warned that the United States may be underinvesting in civilian technology. Among other things, these economists point out that the marginal social rates of return from investments in civilian technology have been very high, both in agriculture and in industry, according to practically every study carried out. Of course, each of these studies has a number of limitations, but overall their conclusions are remarkably consistent.

The government can stimulate additional R&D in the private sector in a variety of ways—by tax credits, R&D contracts and grants, expanded work in government laboratories, altered regulatory policies, and prizes. Although many economists suspect that underinvestment exists in certain areas of civilian technology, at the same time some voice concern that the federal government, in trying to improve matters, could do more

[5] See Nelson, Peck, and Kalachek (1967) and also Nelson (1959).

harm than good.[6] In this regard, the following five guidelines may be of use.

First, a program to stimulate R&D in the private sector should be characterized by flexibility, small-scale probes, and parallel approaches. In view of the relatively small amount of information available and the great uncertainties involved, the research should be organized, at least in part, to provide information concerning the possible returns from a larger program. On the basis of the information that results, a more informed judgment could be made concerning the desirability of increased or, for that matter, perhaps decreased amounts of government support for R&D in the private sector.

Second, any temptation to focus the program on economically beleaguered industries should be rejected. The fact that an industry is in trouble, or that it is declining, or that it has difficulty competing with foreign firms is, by itself, no justification for additional R&D. More R&D may not have much payoff there or, even if it does, the additional resources may have a bigger payoff elsewhere in the economy. It is important to recall the circumstances under which the government is justified in augmenting private R&D. Practically all economists would agree that such augmentation is justifiable only if the private costs and benefits derived from R&D do not adequately reflect the social costs and benefits. But many industries show little or no evidence of a serious discrepancy of this sort between private and social costs and benefits. Indeed, some industries may spend too much, from society's point of view, on R&D.

Third, except in the most unusual cases, the government should avoid getting involved in the later stages of development work. In general, this is an area where firms are far more adept than government agencies. While situations may exist where development costs are so high that private industry cannot obtain the necessary resources, or where it is so important to our national security or well-being that a particular technology be developed that the government must step in, such cases do not arise very often. Instead, the available evidence indicates that, when governments become involved in what is essentially commercial development, they are not very successful at it.

Fourth, in any selective government program to increase support for civilian technology, it is vitally important that a proper coupling occur between technology and the market. In choosing areas and projects for support, the government should be sensitive to market demand. To the extent that it is feasible, potential users of new technology should play a

[6] See U.S. Congress, Office of Technology Assessment (1995); Eisner, Albert, and Sullivan (1986); Council of Economic Advisers (1994); and U.S. General Accounting Office (1996).

role in project selection. Information transfer and communication between the generators and the potential users of new technology are essential, if the innovation is to be successfully applied. As evidence of the importance of this guideline, studies show that a sound coupling of technology and marketing is one of the characteristics most significant in distinguishing firms that are relatively successful innovators from those that are not (Freeman 1973).

Fifth, in formulating any such program, it is important to recognize the advantages of pluralism and decentralized decision-making. If the experience of the last 30 years has taught us anything, it has taught us how difficult it is to plan technological development. Technological change, particularly of a major or radical sort, is marked by great uncertainty. It is difficult to predict which of a number of alternative projects will turn out best, and very important concepts and ideas come from unexpected sources. It would be a mistake for a program of this sort to rely too heavily on centralized planning. Moreover, it would be a mistake if the government attempted to carry out work that private industry can do better or more efficiently.

The Patent System

One of the major instruments of national policy regarding technology is the patent system. Since the Congress passed the original patent act in 1790, the arguments used to justify the existence of the patent laws have not changed very much. First, these laws are regarded as an important incentive to induce the inventor to put in the work required to produce an invention. Particularly in the case of the individual inventor, it is claimed that patent protection is a strong incentive. Second, patents are regarded as a necessary incentive to induce firms to carry out the further work and make the necessary investment in pilot plants and other items that are required to bring the invention to commercial use. If an invention became public property when made, why should a firm incur the costs and risks involved in experimenting with a new process or product? Another firm could watch, take no risks, and duplicate the process or product if it were successful. Third, it is argued that, because of the patent laws, inventions are disclosed earlier than otherwise; as a consequence, other inventions are facilitated by the earlier dissemination of the information.

Not all economists agree that the patent system is beneficial. A patent represents a monopoly right, although it is often a very weak one. Critics of the patent system stress the social costs arising from the monopoly. They point out that, after a new process or product has been discovered, it may cost little or nothing for other persons who could make use of this knowledge to acquire it. (However, the cost of technology transfer frequently is substantial.) The patent gives the inventor the right to charge a price for the use of the information, with the result that the knowledge is used less widely than is socially optimal. Critics also point out that patents have been used to create monopoly positions that were sustained by other means after the original patents had expired; they cite as examples the aluminum, shoe machinery, and plate glass industries. Further, the cross-licensing of patents often has been used by firms as a vehicle for joint monopolistic exploitation of their market.

Critics also question the extent of the social gains arising from the system. They point out that the patent system was designed for the individual inventor, but that over the years most research and development has become institutionalized. They assert that patents are not really important as incentives to the large corporation, since it cannot afford to fall behind in the technological race, regardless of whether or not it receives a patent. They also assert that, because of long lead times, most of the innovative profits from some types of innovations can be obtained before imitators can enter the market. Also, they say that firms keep secret what inventions they can, and patent those they cannot.

Patents are much more important in some industries than in others.[7] Among a random sample of 100 U.S. firms from 12 industries (excluding very small firms), patent protection was judged to be essential for the development or introduction of 30 percent or more of the inventions in only two industries—pharmaceuticals and chemicals. In another three industries (petroleum, machinery, and fabricated metal products), patent protection was estimated to be essential for the development and introduction of 10 to 20 percent of their inventions. In the remaining seven industries (electrical equipment, office equipment, motor vehicles, instruments, primary metals, rubber, and textiles), patent protection was judged to be of much more limited importance (Mansfield 1986). According to another study, product patents were regarded as much more important by the drug and organic chemical industries than by most others, and process patents were regarded as most important by the drug and chemical industries (Levin, Klevorick, Nelson, and Winter 1987).

Without question, the patent system enables innovators to appropriate a larger portion of the social benefits from their innovations than would be the case without it, but patents may not be very effective in this regard. Contrary to popular opinion, patent protection does not make market entry by imitators impossible, or even unlikely. Within four years of their introduction, 60 percent of the patented successful innovations included in one study had been imitated. Nonetheless, patent protection generally increases the cost (to the imitator) of imitation. According to Mansfield, Schwartz, and Wagner (1981), the median estimated increase in imitation cost was 11 percent. Patents had the biggest impact on

[7] See Mansfield (1995a, 1995b, 1995c, 1986); Ordover (1991), and Scotchmer (1991).

imitation costs in the ethical drug industry, a finding that helps to explain why patents are regarded as more important in ethical drugs than elsewhere. (The median increase in imitation cost was about 30 percent in ethical drugs, in contrast to about 10 percent in chemicals and about 7 percent in electronics and machinery.)

Do the benefits derived from the patent system outweigh its costs? Like many broad issues of public policy, the facts are too incomplete and too contaminated by value judgments to permit a clear-cut, quantitative estimate of the effects of the patent system. Nonetheless, few leading economists, if any, favor abolition of the patent system. Even those who publish their agnosticism with respect to the system's effects admit that it would be irresponsible, on the basis of our present knowledge, to recommend abolishing it.

Technological Change and Antitrust Policy

Finally, a considerable amount has been written by economists concerning the effects of market structure and antitrust policy on the rate of technological change. Although we are far from having final or complete answers, the following generalizations seem warranted, based on the available evidence.

The role of the small firm is very important at the stage of invention and the initial, relatively inexpensive stages of R&D. Studies indicate that small firms and independent inventors play a large, perhaps a disproportionately large, role in conceiving major new ideas and important inventions. Further, although full-scale development often requires more resources than small firms command, the investment required for development and innovation is seldom so great or so risky that only the largest firms in an industry can undertake the innovating or the developing. Studies of the drug, coal, petroleum, and steel industries indicate that, in all of these industries, the firms that carried out the most innovations, relative to their size, were not the biggest firms. However, in the chemical industry, the largest firm was the most innovative relative to its size.[8]

A variety of surveys have been made of the empirical evidence regarding the most favorable conditions for industrial innovation. Wesley Cohen and Richard Levin (1989) conclude that "[T]he effects of firm size and concentration on innovation, if they exist at all, do not appear to be important." Others come to essentially the same conclusion, although threshold effects are recognized. F.M. Scherer (1992) summarizes the situation as follows:

[8] See Acs and Audretsch (1990); Jewkes, Sawers, and Stillerman (1970); Hall (1993); von Hippel (1988); Hirshleifer (1973); and Kamien and Schwartz (1982).

> Even though idea-rich small firms originate a disproportionate share of innovations, most small enterprises are not particularly innovative. Large companies may carry their new technologies to a higher degree of perfection than small firms, and . . . they may excel at certain kinds of innovative activities. But neither giant company size nor a high degree of seller concentration appears necessary to maintain a vigorous pace of technological advance. Keeping markets open to new entrants with novel ideas—a notion closer to the Schumpeterian vision of 1912 than to his 1942 view—seems a more important condition for progress.

Two other points should be noted. First, new firms and firms entering new markets play a very important role in the process of technological change. Existing firms can be surprisingly impervious to new ideas, and one way that their mistakes and inertia can be overcome in our economy is through the entry of new firms. Second, economists generally agree that the ideal market structure from the point of view of promoting technological change is one characterized by a mixture of firm sizes. Complementarities or interdependencies exist among firms of various sizes. A division of labor often occurs, with smaller firms focusing on areas requiring sophistication and flexibility and catering to specialized needs, and bigger firms focusing on areas requiring larger production, marketing, or technological resources.

Thus, the available evidence does not indicate that we must permit very great concentration of American industry in order to achieve rapid technological change and the rapid adoption of new techniques. Instead, it seems to suggest that public policy should try to eliminate unnecessary barriers to entry and to promote competition in American industry.

Conclusions

Without question, government policy has a major impact on the rate of technological change. The federal government supports about 35 percent of the research and development in the United States, the impact being greatest in defense, space, and health. But the effects extend far beyond these areas. In terms of dollar support, the federal government (particularly the National Science Foundation, the Department of Defense, and the National Institutes of Health) provided about two-thirds of the funding for academic researchers cited by the information processing, electronics, chemical, instruments, pharmaceutical, metals, and petroleum industries as having made significant contributions to innovations in these industries during the 1980s (Mansfield 1995d).

Controversy has been continual over the past 35 years with regard to the proper role of the federal government in supporting civilian technology. Since pure theory cannot provide unambiguous guidance, a variety of empirical studies have been carried out. The results, while subject to many limitations, seem to indicate that the social rate of return from R&D

is very high, generally about 30 to 50 percent. Also, some evidence has been found that the gap between social and private rates of return tends to be greater for more important innovations and for innovations that can be imitated relatively cheaply by competitors.

There seems to be considerable reason to pursue small-scale efforts to shed light on the desirability of increased support for various types of civilian technology. However, such efforts hold many potential pitfalls. In particular, the temptation to focus programs on economically beleaguered industries should be resisted; the government should avoid getting involved in the later stages of development work; a proper coupling should occur between technology and the marketplace; and it is important to recognize the advantages of pluralism and decentralized decision-making.

In recent years, the federal government has set in motion a variety of technology programs, including the National Institute of Standards and Technology's Advanced Technology Program, which has devoted hundreds of millions of dollars to projects aimed at the development and commercialization of technologies with high potential payoff. Given the controversy over this program in the Congress, the need for more and better information concerning the social rate of return from the resources allocated to this program is obvious. It seems doubtful that estimates based on forecasted data at the beginning of projects will be very accurate, but with updating as commercialization and diffusion occur, valuable information can be obtained concerning social rates of return, as well as the size of forecast errors and how one can devise and use early estimates in a civilian technology program of this sort.[9]

The patent system also remains a topic of considerable controversy. Except for a relatively narrow slice of the economy, in particular pharmaceuticals and chemicals, patents tend to be of secondary importance. However, few leading economists, if any, favor abolition of the patent system. Indeed, one of the interesting developments in recent years has been a growing recognition that the strength or weakness of a country's system of intellectual property protection seems to have a substantial effect, particularly in high-technology industries, on the kinds of technology transferred by foreign firms to that country. Also, this factor seems to influence the composition and extent of U.S. foreign direct investment, although the size of the effects seems to differ greatly from industry to industry.[10]

Economists have shown a keen and continuing interest in the effects of antitrust policy on technological change. In general, the effects of firm size and industrial concentration on the rate of innovation do not appear

[9] See Mansfield (1995b).
[10] See Mansfield (1995a, 1995c) and Lee and Mansfield (1996).

to be of major consequence. Complementarities and interdependencies are found among firms of varying sizes. Accordingly, most analysts agree that we should try to eliminate unnecessary barriers to entry and to promote competition in American industry, since achieving rapid technological change and the rapid adoption of new techniques does not require a high level of industrial concentration.

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DISCUSSION

Samuel S. Kortum*

Edwin Mansfield has made an enormous contribution to our understanding of the economics of technological change. His papers are distinctively direct. To learn about the excess social return to innovation, Mansfield et al. (1977) collected detailed information on a sample of innovations and calculated, for each one, the social and private return. The median social rate of return was over 50 percent, roughly twice the median private return. To learn what patents do, Mansfield, Schwartz, and Wagner (1981) asked firms how patenting an innovation affected the cost and time required for a competitor to imitate it. Patenting raised the cost of imitation on average 10 percent, yet most patented innovations were imitated within four years anyway. To learn about the international transfer of technology, Mansfield and Romeo (1980) asked U.S.-based firms how many years elapsed between the introduction of a new technology in the United States and its transfer to an overseas subsidiary. The mean lag was six years for subsidiaries in developed countries and 10 years for subsidiaries in developing countries. Because direct evidence of this sort is all too rare, I keep Mansfield's articles handy.

In the current paper, Mansfield examines the question: Can policy-makers spur or deter technological change? Mansfield conducts an informed review of the different government practices that could potentially influence the rate of technological change: research performed by government, research funded by government, research subsidized by government, patent protection, and antitrust policy. He surveys the arguments for a government role in promoting research and suggests

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some guidelines for government intervention. Mansfield concludes: Yes, "government policy has a major impact on the rate of technological change."

At first glance his conclusion appears obvious. How could the federal government—performing 10 percent of U.S. R&D, directly funding 35 percent of it (NSF 1995), and giving it special tax treatment—not have a major impact on technological change? There are two possibilities. First, government policies may have had little effect on incentives to perform research. Second, technological change may not be very responsive to incentives. For example, the rate of technological change may have more to do with the arrival of technological opportunities than with the number of researchers attempting to exploit them. Perhaps, as Francis Bacon put it, "Time is the greatest innovator."[1]

I will use an economic model to show that this second possibility is not so easy to debunk. The logic is simple. Innovations will have value as long as they cannot be freely imitated. Researchers will therefore compete for innovations whether or not R&D effort, on the margin, leads to new discoveries. Thus, a world in which R&D is simply a way of dividing the pie will be difficult to distinguish from a world in which the marginal R&D expenditure leads to innovations that would not otherwise have occurred.

Before launching into this argument, I offer a note of caution. The fact that a model of exogenous technological change is difficult to reject does not imply that it is correct. Nonetheless, formulating it will serve to highlight where our understanding of technological change is weak, and hence where our policy advice is shaky.

ENDOGENOUS R&D—EXOGENOUS TECHNOLOGICAL CHANGE

To be credible, a model of exogenous technological change must fit some basic facts related to R&D and its correlation with other economic variables. A simple model of perfect competition can be rejected because it will not account for any private investment in R&D.

A good starting point instead is Arrow (1962): The owner of a patented process innovation licenses it to producers in a competitive industry in return for a royalty payment.[2] Suppose that the demand for industry output, at price p, is simply $y = S/p$, where S is a demand shifter (equal to the value of industry sales). At a point in time, unit production

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[1] Bacon is quoted by Merton (1961, p. 349) in an essay on multiples in science (the multiple discovery of the same thing).

[2] This is also an interpretation of the framework described in the section of Mansfield's paper entitled "Measuring Social Benefit from New Technology," under the special case where the innovator has all the bargaining power, so that $P_2 = P_1$.

cost is a constant c. It follows that the royalty rate for a process innovation is the reduction in unit cost it makes possible.

Arrow's model of the incentive to innovate says nothing about where innovations come from. In the spirit of Bacon, assume that time generates one opportunity for a process innovation each year. An innovation, if developed and adopted, leads to a fixed percentage reduction in unit cost, as in the quality ladders model of Grossman and Helpman (1991). For example, if unit cost is c_{t-1} in year $t - 1$, then after the year t innovation is adopted the unit cost falls to $c_t = \frac{c_{t-1}}{1+\gamma}$. The parameter $\gamma > 0$ can be thought of as the 'size' of an innovation. Suppose for simplicity that patent protection applies only to the state-of-the-art process at any point in time. Competition will result in zero royalties for all but the most recent innovation. The royalty rate in year t will therefore be $c_{t-1} - c_t = \gamma c_t$. Under perfect competition, the industry price in year t is the sum of unit production cost and the royalty rate, $p_t = (1 + \gamma)c_t$. The total royalty received by the owner of the patent on the innovation adopted in year t is therefore

$$V_t = (\gamma c_t)y_t = \frac{\gamma}{1+\gamma} p_t y_t = \frac{\gamma}{1+\gamma} S.$$

In what sense is technological change exogenous? Suppose that an innovative opportunity can be developed by a researcher at a cost of d, and would then be adopted the following year. Which researcher is 'first to invent' and hence able to patent the innovation? After committing to R&D investments of d, each researcher will develop the invention at some time during the year. Who is first to invent is determined by chance; if there are n researchers, they each face a $1/n$ chance of being first.[3] With free entry into research, and ignoring the integer problem, n should satisfy $d = \frac{1}{n}\frac{V}{1+r}$, where r is the interest rate. It is assumed throughout that the parameters satisfy $\frac{\gamma S}{d(1+\gamma)(1+r)} \geq 2$ (so that $n \geq 2$), and hence each innovation will be developed with or without the help of the last researcher. Annual R&D expenditures in the industry are given by

[3] This model of research is a special case of Tandon (1983). Notice that multiple 'discoveries' of the same thing (multiples) generally will occur. Merton (1963) argues that multiples are ubiquitous, but he envisions a more sophisticated model in which more parallel research increases the probability of someone making a discovery. He suggests that there is an optimal amount of redundancy in research, being "that amount which will approximate a maximum probability of achieving the wanted outcome but not so great an amount that the last increment will fail appreciably to enlarge that probability" (p. 380). These concepts are formalized in the general case of Tandon's model.

$$R = nd = \frac{V}{1+r} = \frac{\gamma S}{(1+r)(1+\gamma)}.$$

The model accounts for private R&D even though (for $R \geq d$) technological change is unrelated to R&D.[4]

Can This Model Fit the Facts?

To convince someone of the importance of R&D in determining the course of technological change, it is natural to point to the vast literature on R&D and productivity surveyed in BLS (1989). Econometric studies have uncovered a systematic relationship between the growth of total factor productivity (TFP) and research intensity (the R&D–sales ratio). Unfortunately, these results do not provide convincing evidence against a model, such as the one laid out above, in which technological change is essentially exogenous.

To see this, assume that the model above held in each of $i = 1, \ldots, N$ industries. Industries might differ according to the value of sales S_i and the size of innovations γ_i. TFP growth in industry i is simply γ_i. Research intensity (RI) in industry i is $R_i/S_i = \dfrac{\gamma_i}{(1+r)(1+\gamma_i)}$. This leads to the equation,

$$TFP_i \approx \frac{(1+r)RI_i}{1-(1+r)RI_i} \approx (1+r)RI_i,$$

where the approximation is adequate for the small values of research intensity that are actually observed. Even though technological change is exogenous, one would get a slope coefficient of $1 + r$ by regressing TFP growth on R&D intensity across the N industries.[5]

This identification problem has been articulated by Griliches (1995, p. 80):

> one may wind up reporting something as an estimate of the effect of R&D on output which may be mostly a reflection of the effect of output on R&D rather than vice versa.

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[4] Note that the last researcher's efforts provide no benefit to society. To my knowledge, Barzel (1968) was the first to present a model in which competition could lead to excessive R&D.

[5] The uncharacteristically large coefficient $(1 + r)$ implied by this model—econometric estimates are closer to 0.3 (Griliches 1995, Table 3.3)—is a result of the simplifying assumption that a new innovation arrives each year, hence there is only one year to recoup R&D expenses.

The model above simply illustrates an extreme example of this conundrum.

I now turn to Mansfield's approach, in earlier work, of directly measuring the rate of return to innovations. In the world described by the simple model of exogenous technological change, the private (internal) rate of return to research is r and the marginal social rate of return to research is -100 percent (that is, the marginal expenditure on research has a cost but confers no benefit to society). What would one conclude by collecting data on innovations? The naive economist, collecting data only from the firm that patents the innovation, would calculate an extraordinarily high social and private rate of return on the winner's small investment in research. A more sophisticated economist would count as expenditure all the research costs of the losing firms as well as the winner. In this way, the private rate of return to research would be calculated correctly as equal to the market return r. (This is exactly the condition that determines the equilibrium level of R&D for the industry.) But the marginal social rate of return would be calculated incorrectly as being greater than r, since the social benefits of the innovation extend indefinitely. The mistake in this calculation is that the social benefit should not be attributed to the marginal expenditure on research.

In principle, Mansfield and his collaborators (1977) would not have been fooled by this problem. As they clearly state,

> we calculated the social benefits only during the period between the date when the innovation occurred and the date when it would have appeared if the innovator had done nothing.

In the world of exogenous technological change described by the model, Mansfield would correctly conclude that each innovation would have occurred even if the innovator had done no research. Nonetheless, one worries that such calculations, based on survey evidence, are sensitive to answers by the innovating firm to hypothetical questions about its competitors. Just as the econometric approach has shortcomings, in practice the direct approach is also very difficult to get right.

Government Policies

It is useful to work through several policies toward research in the framework of the model above, even though each policy will, by assumption, have no effect on technological change. First, consider research performed by the government. Suppose that a government researcher acts like a private researcher, attempting to lay claim to a new innovation but then making it available to producers in return for a royalty. In that case, if government research in the industry is less than the equilibrium level of research, government research simply crowds out private research and the total level of research is unchanged by the government intervention.

A government subsidy of research will work somewhat differently. A 10 percent subsidy will lead researchers to raise their gross-of-subsidy expenditures by 10 percent so that their net-of-subsidy expenditures are left unchanged. Thus, the research subsidy will be successful at raising research activity, although it will not alter the rate of technological change.

A policy of strengthening patent protection can also be analyzed with this model. Let θ index the strength of patent protection: With probability θ, patent protection prevents imitation for exactly one year, otherwise imitation is immediate despite patent protection. Under this generalization of the model, equilibrium R&D is $R = \frac{\theta \gamma S}{(1 + r)(1 + \gamma)}$. It is increasing in the strength of patent protection, as is R&D intensity.[6] In this model, strengthening patent protection raises R&D and lowers consumer surplus (since goods are less frequently supplied at marginal cost) but has no effect on technological change.

Conclusion

The government's ability to spur technological change depends ultimately on the responsiveness of technological change to research efforts. But not much evidence is available about the true elasticity of technological change with respect to research effort. A model of endogenous R&D and exogenous technological change (in which the true elasticity is zero) is surprisingly hard to reject. Mansfield's own calculations of the social return to research stand up well to this scrutiny but, as he admits, "Certainly, they are very frail reeds on which to base policy conclusions."

I conclude on a more optimistic note. An econometric analysis of a specific policy change could provide key evidence on the issue of how technological change responds to research. Take, for example, the increased protection that patents have received since the Congress, in 1982, created the Court of Appeals of the Federal Circuit. An unprecedented

[6] The model needs to be slightly enriched in order for the strength of patent protection to influence the fraction of innovations that are patented. Suppose that γ is drawn from a known distribution F after R&D decisions are made but before the patenting decision is made. For simplicity assume that unpatented innovations are imitated immediately. If patenting has a cost, then innovations whose size is below some threshold will not be protected (the R&D equation must also be modified to reflect this option value of patenting). If the strength of patent protection increases relative to the cost of patenting, then the fraction of innovations that are patented will rise. A model of this sort is used by Eaton and Kortum (1996) to infer patterns of international technology diffusion from patterns of international patenting.

burst of patenting activity in the United States resulted; nothing like it had been seen in the past 70 years.

It may be difficult to conclude much from the aggregate time series, but this policy change is likely to have hit different industries differently. Both Mansfield, Schwartz, and Wagner (1981) and Levin et al. (1987) report great variation across industries in the importance of patents. One would expect to see research intensity rise by more in those industries in which patents are an important means of appropriating the fruits of R&D. If technological change is exogenous, then variation in R&D intensity generated by a change in policy would have no impact on productivity. Hence, if industry-level productivity has responded in a systematic way to policy-induced changes in research intensity, this would be persuasive evidence of government's ability to influence technological change.

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Discussion

Joshua Lerner*

Edwin Mansfield's thoughtful review of the literature on the economics of technological change raises a variety of interesting issues, far too many to address in a few pages. Consequently I will focus my discussion on the section that I found most challenging and thought-provoking—his prescriptions for policymakers, in the section "Public Policy toward Civilian Technology." In particular, my discussion revisits these recommendations with a particular question in mind: Should public technology policy be affected by the fact that a disproportionate number of radical innovations are generated by small firms? Viewing his policy prescriptions through these lenses may help enrich the discussion.

The Important Role of New Entrants

As Mansfield observes in a later section, "Technological Change and Antitrust Policy," one of the empirical regularities emerging from studies of technological innovation is the role played by new entrants. From the pioneering study of Jewkes, Sawers, and Stillerman (1958), Acs and Audretsch (1988), and other works, economists have gradually realized that these young firms often play a key role in identifying where new technologies can be applied to meet technological needs, and in rapidly introducing products. (These patterns are also predicted in several models of technological competition, many of which are reviewed in Reinganum 1989.) While several studies suggest that established firms

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have a substantial advantage in incremental innovation, small firms appear to generate a disproportionate share of radical breakthroughs.

The 1990s have seen several dramatic illustrations of this pattern. Two potentially revolutionary areas of technological innovation—biotechnology and the Internet—were pioneered by smaller entrants, typically backed by venture capital investors. Neither established drug companies nor mainframe computer manufacturers were pioneers in developing these technologies. By and large, small firms did not invent the key genetic engineering techniques or the Internet protocols. Rather, the bulk of the enabling technologies were developed with federal funds at academic institutions and research laboratories. It was the small entrants who were the first to seize upon the commercial opportunities. In some cases, these new firms—utilizing the capital, expertise, and contacts provided by their venture capital investors—established themselves as market leaders. In other instances, they were acquired by larger corporations or entered into licensing arrangements with such concerns.

These patterns can only be expected to occur more frequently in coming years. The pool of venture capital has expanded eightfold (in inflation-adjusted dollars) since 1978, vastly increasing the resources available for young technology-based firms. While the share of venture resources going to seed and early-stage firms (as opposed to expansions or buyouts of already profitable concerns) dipped in the mid 1980s, in recent years an increasing share of venture capital disbursements has gone to early-stage firms. Meanwhile, National Science Foundation tabulations suggest that the share of total industrial R&D spending accounted for by major corporations has fallen considerably.[1]

Innovation and the Market Test

How should these patterns affect the design of U.S. technology policy? While Professor Mansfield thoughtfully lays out five criteria for the assessment of technology programs, I believe that one of these might be rethought in light of these patterns, and that an additional consideration might be added.

First, given this pattern of innovation, I am somewhat skeptical of his claim that "it is vitally important that a proper coupling occur between

[1] Data on venture capital fund-raising and disbursements are available in the various publications of Venture Economics and VentureOne. Recent data on research and development expenditures by firms of different sizes are available in National Science Board (1996). It is still important to point out that disbursements by venture capital funds (which go for a wide variety of purposes in addition to R&D, such as capital expenditures and salaries) are vastly smaller than R&D performed by major American corporations. In fact, in the years 1970 through 1994, total annual disbursements of the venture capital industry never exceeded the R&D expenditures of *either* IBM or General Motors.

technology and the market." Mansfield argues that the federal government's technological investments should be made in conjunction with potential users. Given the unexpected nature of many of the radical discoveries and the critical role of previously unknown entrants, this approach seems problematic—perhaps even counterproductive.

Consider what would have been the fate of the Department of Defense's funding of the development of the Internet during the 1960s, or the National Institutes of Health's funding of genetic engineering research during the early 1970s, had federal program officers been required to obtain agreement that these technologies were commercially relevant from executives in the research departments of the major computer and pharmaceutical companies (or, even more improbably, had they been required to obtain matching funds from these organizations). This research would have never been undertaken had it not been motivated by the agencies' missions of providing a strong national defense and better health. To add such a market test would likely harm federal officials' ability to fund very long-run research.

Addressing Threats to New Entrants

Second, if new entrants are playing a vital role in introducing radical innovations, addressing several threats to their future development should be a priority. The area that I believe deserves particular attention relates to intellectual property protection, particularly patents. The U.S. patent system has undergone a profound shift over the past 15 years. The strength of patent protection has been dramatically bolstered, and both large and small firms are devoting considerably more effort to seeking patent protection and defending their patents in the courts. Many in the patent community—officials of the U.S. Patent and Trademark Office, the patent bar, and corporate patent staff—have welcomed these changes. But viewed more broadly, the reforms of the patent system and the consequent growth of patent litigation have created a substantial "innovation tax" that afflicts some of America's most important and creative small firms.[2]

Almost all formal disputes involving issued patents are tried within the federal judicial system. The initial litigation must be undertaken in a district court. Prior to 1982, appeals of patent cases were heard in the

[2] One question raised by this argument is, if these obstacles are important, why has the share of R&D expenditures being undertaken by small firms substantially increased in recent years? The rapid pace of change in many facets of information and communications technology may have created more opportunities for newer organizations. Many observers have noted the difficulties that established organizations have had in responding to rapid technological change: for one example, see Jensen's (1993) discussion of the "major inefficiencies [that exist] in the R&D spending decisions of a substantial number of firms."

appellate courts of the various circuits, which differed considerably in their interpretation of patent law. Because few appeals of patent cases were heard by the Supreme Court, substantial differences persisted, leading to widespread "forum shopping" by litigants.

In 1982, the U.S. Congress established a centralized appellate court for patent cases, the Court of Appeals for the Federal Circuit (CAFC). As Robert Merges (1992) observes:

> While the CAFC was ostensibly formed strictly to unify patent doctrine, it was no doubt hoped by some (and expected by others) that the new court would make subtle alterations in the doctrinal fabric, with an eye to enhancing the patent system. To judge by results, that is exactly what happened.

The CAFC's rulings have been more "pro-patent" than those of the previous courts. For instance, the circuit courts had affirmed 62 percent of district court findings of patent infringement in the three decades prior to the creation of the CAFC, while the CAFC in its first eight years affirmed 90 percent of such decisions (Koenig 1980; Harmon 1991).

The strengthening of patent law has not gone unnoticed by corporations. Over the past decade, the number of patents awarded to U.S. corporations has increased by 50 percent. Furthermore, the willingness of firms to litigate patents has increased considerably. The number of patent suits instituted in the federal courts increased from 795 in 1981 to 1553 in 1993; adversarial proceedings within the U.S. Patent and Trademark Office increased from 246 in 1980 to 684 in 1992 (Administrative Office, various years; U.S. Department of Commerce, various years). My recent analysis of litigation by firms based in Middlesex County, Massachusetts, suggests that six suits related to intellectual property are filed for every 100 patent awards to corporations.

These suits lead to significant expenditures by firms. Based on historical costs, I estimate that patent litigation begun in 1991 will lead to total legal expenditures (in 1991 dollars) of over $1 billion, a substantial amount relative to the $3.7 billion spent by U.S. firms on basic research in 1991. (These findings are summarized in Lerner 1995.) Litigation also leads to substantial indirect costs. The discovery process is likely to require the alleged infringer to produce extensive documentation, involve time-consuming depositions from employees, and generate unfavorable publicity. The firm's officers and directors may also be held individually liable.

As firms have realized the value of their patent positions, they have begun reviewing their stockpiles of issued patents. Several companies, including Texas Instruments, Intel, Wang Laboratories, and Digital Equipment, have established groups that approach rivals to demand royalties on old patent awards. In many cases, they have been successful in extracting license agreements or past royalties. For instance, Texas

Instruments is estimated to have netted $257 million in 1991 from patent licenses and settlements resulting from their general counsel's aggressive enforcement policy (Rosen 1992).

Particularly striking, practitioner accounts suggest, has been the growth of litigation—and threats of litigation—between large and small firms.[3] This trend is disturbing. While litigation is clearly a necessary mechanism to defend property rights, the proliferation of such suits may lead to transfers of financial resources from some of the youngest and most innovative firms to more established, better capitalized concerns. Even if the target firm believes that it does not infringe, it may choose to settle rather than fight. It may be unable to raise the capital to finance a protracted court battle, or it may believe that the publicity associated with the litigation will depress the valuation of its equity.

In addition, these small firms may reduce or alter their investment in R&D. For instance, a 1990 survey of 376 firms found that the time and expense of intellectual property litigation was a major factor in the decision whether to pursue an innovation for almost twice as many firms with under 500 employees as for larger businesses (Koen 1990). These claims are also supported by my study (1995) of the patenting behavior of new biotechnology firms that have varying litigation costs. I showed that firms with high litigation costs are less likely to patent in subclasses with many other awards, particularly those of firms with low litigation costs.

These effects have been particularly pernicious in emerging industries. Chronically strained for resources, U.S. Patent and Trademark Office officials are unlikely to assign many patent examiners to emerging technologies in advance of a wave of applications. As patent applications begin flowing in, the U.S. Patent and Trademark Office frequently finds the retention of the few examiners skilled in the new technologies difficult. Companies are likely to hire away all but the least able examiners. These examiners are valuable not only for their knowledge of the examination procedure in the new technology, but also for their understanding of what other patent applications are in process but not yet awarded. (U.S. patent applications are held confidential until time of award.) Many of the examinations in emerging technologies are, as a result, performed under severe time pressures by inexperienced examiners. Consequently, awards of patents in several critical new technologies have been delayed and highly inconsistent. These ambiguities have created ample opportunities for firms that seek to aggressively litigate their patent awards. The clearest examples of this problem are to be found in the biotechnology and software industries.

[3] Several examples are discussed in Chu (1992). Examples include the dispute between Cetus Corporation and New England Biolabs regarding the taq DNA polymerase and that between Texas Instruments and LSI Logic regarding semiconductor technology.

CONCLUSION

In conclusion, I concur in large part with Mansfield's thoughtful and well-reasoned policy recommendations. My main concern is that we avoid taking steps in the name of increasing competitiveness that actually interfere with the workings of the American system of innovation. The 1982 reforms of the patent litigation process have had exactly this sort of unintended consequence; and I fear that any efforts to make federal research more commercially relevant will do likewise.

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