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6 R & D and Innovation: Some Empirical Findings

Edwin Mansfield

6.1 Introduction

Until about twenty years ago, economists neglected the study of technological change, with adverse effects on both the quality and usefulness of economic analysis. During the past twenty years, a substantial corpus of knowledge has been developed in this area, and much of it is being used by policymakers in both the public and private sectors. Despite the advances that have been made, the gaps in our knowledge are great. The economics of technological change, while healthy and growing, is still at the stage where many of the basic facts, and theories are missing.

In the past two years, I have been engaged in a number of interrelated studies of R & D, innovation, and technological change. These studies have been concerned with a variety of topics, ranging from the composition of R & D expenditures to international technology transfer, from price indexes for R & D inputs to the effects of government R & D on private R & D. At this point, many of these studies have reached the point where some of the major findings are in hand, even though much more remains to be done before our understanding of the relevant topics is reasonably satisfactory.

The purpose of this paper is to bring together and discuss some of the empirical findings that have emerged. To keep the paper to a reasonable length, I shall have to be very selective and brief. Only a few findings of

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each study can be presented. In a sense, this paper provides a partial and preliminary overview of some of the recent work I have been doing in this area. Since the various studies are interrelated in many ways, such an overview should be useful.

6.2 Composition of R & D: Effects and Determinants

To begin with, let's consider the composition of R & D expenditures. In my opinion, economists have devoted too little attention to this topic. For both analytical and policy purposes, the total R & D figures are hard to interpret because they include such a heterogeneous mixture of activities. Basic research and applied research are mixed up with development. Long-term projects are mixed up with short-term projects. Projects aimed at small product and process improvements are mixed up with projects aimed at major new processes and products. Process R & D is mixed up with product R & D. To answer many important analytical and policy questions, it is essential to disaggregate R & D.

Unfortunately, little work has been done on this score. To help fill this gap, I have tried to (1) estimate the effects of the composition of an industry's or firm's R & D expenditures on its rate of productivity increase (when its total R & D expenditures are held constant), (2) investigate the relationship between the composition of a firm's R & D expenditures and its innovative output, as measured by the number of major innovations introduced, and (3) determine what factors are associated with the composition of a firm's R & D expenditures, with particular attention being directed at firm size and industrial concentration.[1]

At least four findings emerge from these studies. First, holding constant the amount spent on applied R & D and basic research, an industry's rate of productivity increase between 1948 and 1966 seems to have been directly related to the extent its R & D was long-term. Although the interpretation of this result is by no means clear-cut, it certainly is suggestive. As pointed out elsewhere,[2] many firms tend to concentrate on short-term, technically safe R & D projects. Particularly in recent years, some observers, including both public policymakers and top officials of the firms themselves, have begun to question the wisdom of this emphasis.

Second, when a firm's total R & D expenditures were held constant, its innovative output seemed to be directly related to the percentage of its R & D expenditures devoted to basic research. The data on which this result is based pertain to the chemical and petroleum industries, areas

1. Some results of these studies have been published in Mansfield (1980). Additional results appear in Mansfield (1981a). Link (1981) also has been investigating factors associated with the composition of R & D.

2. For recent evidence on this subject, see Mansfield (1981b).

where we have accumulated a considerable amount of data concerning the R & D and innovative activities of particular firms. It would be extremely useful if a similar investigation could be made of other industries. In view of the roughness of both the data and the analysis, this finding should be viewed as preliminary and tentative. In particular, it is hard to tell whether basic research is the relevant variable, or whether it is a surrogate for something else.

Third, based on data obtained from 108 firms that account for about one-half of all industrial R & D expenditures in the United States, the composition of a firm's R & D expenditures appears to be related to the firm's size. But the relationship is not as simple as one might think. Whereas the largest firms seem to carry out a disproportionately large share of the basic research (and perhaps the long-term R & D) in most industries, they do not tend consistently to carry out a disproportionately large share of the relatively risky R & D or the R & D aimed at entirely new products and processes. Instead, they generally seem to carry out a disproportionately small share of the R & D aimed at entirely new products and processes. These results are not contradictory. Basic research is by no means the same thing as R & D aimed at entirely new products and processes. Also, since both basic research and applied R & D can be relatively risky, the riskiness of a firm's R & D need not be closely correlated with the percentage of its R & D devoted to basic research.

Fourth, the more concentrated industries in our sample seem to devote a smaller, not larger, percentage of R & D expenditures to basic research. This relationship is statistically significant, but not very strong ($r^2 = .46$). Relatively concentrated industries also tend to devote a relatively small, not large, proportion of their R & D expenditures to long-term projects and to projects aimed at entirely new products and processes, but the correlation (in each case r^2 is about .09) is far from statistically significant. A positive correlation does exist ($r^2 = .15$) between an industry's concentration level and the proportion of its R & D expenditures going for relatively risky projects, but this correlation too is far from significant.

6.3 Price Indexes for R & D Inputs

Not only is relatively little known about the composition of R & D expenditures, but equally important, the available data concerning real R & D expenditures are bedeviled by the lack of a suitable price index for R & D inputs. In view of the inherent difficulties and the strong assumptions underlying the few alternative measures that have been proposed, the official government R & D statistics use the GNP deflator to deflate R & D expenditures. Many observers inside and outside the government are uncomfortable with this procedure, but little is known about the size or direction of the errors it introduces.

To help fill this gap, we constructed price indexes for R & D inputs and for inputs used in other stages of the innovative process. Detailed data were obtained from thirty-two firms in the following eight industries: chemicals; petroleum; electrical equipment; primary metals; fabricated metal products; rubber; stone, clay, and glass; and textiles. These industries account for about half of the company-financed R & D in the United States. Although our sample contains both large and small firms, it includes a substantial proportion of the R & D carried out in these industries. Indeed, the firms in our sample account for about one-ninth of all company-financed R & D in the United States.[3]

At least four findings stem from this study. First, for these industries as a whole, the Laspeyres price index for R & D inputs indicates that the price of such inputs was about 98 percent higher in 1979 than in 1969. However, the rate of inflation in R & D seems to have been higher in some industries than in others. In particular, the rate of inflation seems to have been highest in fabricated metal products, chemicals, and petroleum, and lowest in electrical equipment.

Second, turning to the innovation process as a whole, Laspeyres price indexes indicate that the price of inputs into all stages of the innovative process was about 101 percent higher in 1979 than in 1969. Thus, the rate of inflation for inputs into all stages of the innovation process seems to have been somewhat higher than for R & D alone. As in the case of R & D, the rate of inflation for inputs into all stages of the innovation process seemed to be highest in fabricated metal products, chemicals, and petroleum, and lowest in electrical equipment.

Third, if we assume that the production function for R & D in each industry is Cobb-Douglas (with constant returns to scale), an exact price index for each industry is

$$I = \prod_{i=1}^{n} \left(\frac{P_{1i}}{P_{0i}} \right)^{\alpha_i} \times 100, \tag{1}$$

where the price of the ith input in 1979 is P_{1i}, its price in 1969 is P_{0i}, α_i is the proportion of R & D cost devoted to the ith input, and n is the number of inputs.[4] Even though there is little or no information concerning the nature of the production function for R & D, it is interesting to compare the resulting indexes with the Laspeyres indexes because, since Laspeyres indexes ignore substitution effects, they may exaggerate price increases. Table 6.1 shows the results for each industry. As you can see,

3. This work is being done with Anthony Romeo and Lorne Switzer. For a preliminary account of some of our findings, see Mansfield, Romeo, and Switzer (1983). For some previous work, see Goldberg (1978) and Jaffe (1972).

4. For a proof of this, see Mansfield, Romeo, and Switzer (1983).

Table 6.1 **Price Indexes for R & D Inputs and for Inputs in the Innovative Process, Eight Industries, 1979 (1969 = 100)[a]**

Industry	Laspeyres Index R & D	Laspeyres Index Innovation Process	Cobb-Douglas R & D
Chemicals	222	223	217
Petroleum	222	228	218
Electrical equipment	183	186	190
Primary metals	205	210	205
Fabricated metal products	248	275	222
Rubber	209	200	206
Stone, clay, and glass	205	195	183
Textiles	200	220	220
Mean[b]	198	201	200

Source: See section 6.3.

[a]The three columns are not entirely comparable because some firms could be included in some columns but not others because of lack of data. For the innovation process, some figures have been rounded to the nearest 5 or 0 to indicate their roughness.

[b]Each industry's price index is weighted by its 1969 R & D expenditure.

those based on the Cobb-Douglas assumption are generally quite similar to those based on the Laspeyres indexes. On the average, the Cobb-Douglas indexes indicate that the price of R & D inputs was about 100 percent higher in 1979 than in 1969.

Fourth, in practically all of the industries included here, the rate of increase of the price index for R & D inputs exceeded the rate of increase of the GNP deflator. Because of the inadequacies of the GNP deflator for this purpose, the official U.S. statistics concerning deflated R & D expenditures seem to overestimate the increase during 1969–79 in industrial R & D performance. For these industries as a whole, deflated R & D expenditures increased by about 7 percent (during the period, not annually) based on the GNP deflator, but only by less than 1 percent based on our price indexes for R & D inputs. Taken at face value, this seems to indicate that the bulk of the apparent increase in real R & D in these industries was due to the inadequacies of the GNP deflator.

6.4 Effects of Federal Support on Privately Financed R & D

Just as the lack of R & D price indexes has long been recognized, the need for more information on the effects of government R & D on private R & D has also long been known. This area has been the subject of considerable controversy. Some economists argue that increases in government R & D funding are likely to reduce expenditures of the private sector because (among other reasons) firms may receive government support for some projects they would otherwise finance themselves. Other economists say that government R & D is complementary to private R & D, that increases in the former stimulate increases in the latter. This question is of great importance for both policy and analysis, but little is known about it.

To study the effects of federal support on privately financed R & D in the important area of energy, we chose a sample of twenty-five major firms in the chemical, oil, electrical equipment, and primary metals industries. Together they carry over 40 percent of all R & D in these industries. To estimate the extent to which these firms obtained government funding for energy R & D projects that they would have carried out in any event with their own funds, we obtained detailed data from each of the firms. Moreover, even more detailed data were obtained concerning a sample of forty-one individual federally funded energy R & D projects. These projects account for over 1 percent of all federally supported energy R & D performed by industries.[5]

The following are four of the conclusions stemming from this study. First, these firms apparently would have financed only a relatively small proportion of the energy R & D that they performed with government support. Based on our sample of firms, they would have financed only about 3 percent on their own. Based on our sample of individual projects, they would have financed about 20 percent. It would be useful if similar estimates could be obtained for various kinds of R & D outside the field of energy.

Second, if a 10 percent increase were to occur in federal funding for their energy R & D in 1979, the response (for all twenty-five firms taken as a whole) would be that, for each dollar increase in federal support, they would increase their own support of energy R & D by about six cents per year for the first two years after the increase in federal funds. In the third year after the increase, there would be no effect at all. This finding is based on careful estimates by senior R & D officials of each firm. However, substantial differences exist among the firms' responses. These results are quite consistent with those obtained by Levin (1981) and Terleckyj and Levy (1981) in their econometric studies of the aggregate relationship between federally funded R & D expenditures and privately funded R & D expenditures.

Third, if a 10 percent cut were to occur in federal funding for their energy R & D in 1979, the response (for all twenty-five firms taken as a whole) would be that, for each dollar cut in federal support, they would reduce their own support of energy R & D by about twenty-five cents in each of the two years following the cut. In the third year after the federal cut, they would cut about nineteen cents in their own spending. Taken at

5. This work is being conducted with Lorne Switzer.

face value, a 10 percent cut in federally funded energy R & D would apparently have a bigger effect on privately funded energy R & D than would a 10 percent increase. But until more and better data are obtained, we feel that this difference should be viewed with considerable caution.

Fourth, in modeling the effects of federally funded R & D on the economy, our results indicate that it may be more realistic to view such R & D as a factor that facilitates and expands the profitability of privately funded R & D, rather than focus solely (as most econometric studies have done) on the direct effects of federally funded R & D on the productivity of the firms and industries performing the R & D. Based on our sample of federally funded projects, such projects typically appear to make only about half as large a direct contribution to the firm's performance and productivity as would be achieved if the firm spent an equivalent amount of money on whatever R & D it chose. But in about one-third of the cases, the federally financed R & D projects suggested some further R & D into which the firm invested its own funds. (As shown in table 6.2, the likelihood of such a spin-off is enhanced if the firm helped to formulate the ideas on which the project is based, and if the project was not completely separated physically from the projects financed by the firm.)[6] If federally funded R & D is viewed in this way, econometricians may have more success in measuring its effects on productivity in the private sector.

6.5 Forecasts of Engineering Employment

Engineering manpower is one of the most important inputs required in the complex process leading to innovation and technological change. Policymakers in government, universities, and business must make decisions that depend, explicitly or implicitly, on forecasts of the number of engineers employed in various sectors of the economy at various times. For example, in evaluating the adequacy of existing engineering manpower, the National Science Foundation and the Bureau of Labor Statistics must try to forecast how many engineers will be employed in the private sector. Although such forecasts sometimes are based on a collection of forecasts made by firms of their own engineering employment, little is known about the accuracy of these forecasts.

To help fill this gap, a detailed econometric study was carried out. Data were obtained from a well-known engineering association which has collected such forecasts from firms for many years. For fifty-four firms in

6. Of course, we recognize the difficulty in many cases of identifying where the ideas underlying a particular project originated. But in the cases in table 6.2, this generally seemed to be a matter of agreement among all parties. Note too that, whereas the source of the project seems to have a statistically significant effect, the separation variable is not significant when both variables are included.

Table 6.2 Percentage of Federally Financed Energy R & D Projects Resulting in Company-Financed R & D Done Subsequently by the Performer, by Source of Idea for Project, and by Extent of Separation from Company-Financed Projects, Forty Projects[a]

Characteristic of Project	Percentage
Source of idea for project:	
Firm	44
Government	15
Both firm and government	44
Separation:	
Complete	17
Not complete	38

Source: See section 6.4.

[a]One project could not be included because it was not yet clear whether it would result in company-financed R & D. The figures in this table may understate the true percentages because they pertain only to company-financed R & D resulting directly and almost immediately from these projects.

the aerospace, electronics, chemical, and petroleum industries, comparisons were made of each firm's forecasted engineering employment with its actual engineering employment during 1957–76. Since data were obtained for a number of forecasts of each firm, the accuracy of 218 such forecasts could be evaluated.[7]

At least three conclusions stem from this study. First, there appear to have been substantial differences among industries in the accuracy of the forecasts. As shown in table 6.3, the forecasting errors for individual firms in the areospace industry were much greater than in the electronics, chemical, or petroleum industries. (In chemicals and petroleum, firms' two-year forecasts were off, on the average, only by about 5 percent.) The relatively large forecasting errors in the aerospace industry may have been caused by its heavy dependence on government defense and space programs which were volatile and hard to predict.

Second, although the forecasting errors for individual firms were substantial, they tend to be smaller when we consider the total engineering employment for all firms in the sample. On the average, the six-month forecasts were in error by about 2 percent, the two-year forecasts were in error by about 1 percent, and the five-year forecasts were in error by about 3 percent. The fact that little bias was present in the forecasts is encouraging since, for many purposes, the central aim is to forecast total engineering employment in an entire sector of the economy, not the engineering employment of a particular firm.

Third, the firms' forecasts may be improved if a simple econometric model is used. Based on data from over a dozen chemical and petroleum

7. This work was done with Peter Brach. Some of the results appear in Brach and Mansfield (1982).

Table 6.3 Frequency Distribution of Forecasts, by Ratio of Forecasted to Actual Engineering Employment, Aerospace, Electronics, Petroleum, and Chemical Industries, Six-Month and Two-Year Forecasts[a]

Forecasted Employment ÷ Actual Employment	Aerospace	Electronics	Petroleum	Chemical
	Number of 6-Month Forecasts			
0.81–0.90	0	1	0	0
0.91–1.00	8	10	12	6
1.01–1.10	7	9	13	9
1.11–1.20	0	2	0	1
1.21–1.30	2	0	0	0
1.31–1.40	2	0	0	0
	Number of 2-Year Forecasts			
0.61–0.70	0	1	0	0
0.71–0.80	2	3	0	0
0.81–0.90	4	3	4	1
0.91–1.00	2	9	8	1
1.01–1.10	3	6	6	5
1.11–1.20	0	0	0	0
1.21–1.30	0	3	0	0
1.31–1.40	3	0	0	0

Source: See section 6.5.

[a]Five-year and ten-year forecasts were also included in the study but are not in this table.

firms, the proportion of the way that a firm's engineering employment moves toward the desired level is inversely related to the desired percentage increase in engineering employment[8] and is directly related to the profitability of the firm. (A similar model was used in Mansfield 1968.) Using information concerning this relationship in the past as well as the firm's desired level of engineering employment in the future, one can forecast the firm's future engineering employment. The evidence, while fragmentary and incomplete, suggests that experimentation with such an approach may be worthwhile.

6.6 International Technology Transfer

To understand a wide variety of topics, ranging from economic growth to industrial organization, economists must be concerned with international technology transfer. In my opinion, economists interested in the

8. This model assumes that desired employment exceeds actual employment, which was the typical case in these firms in the relevant time periods. Obviously, this model should be used only in cases where this assumption is true.

relationship between R & D and productivity increase have paid too little attention to this subject. In practically all econometric models designed to relate R & D to productivity increase, international technology flows are not included (explicitly at least). Yet U.S.-based firms carry out about 10 percent of their R & D overseas, and this R & D has an effect on the rate of productivity increase in the United States. In addition (and probably more important), R & D carried out by one organization in one country often has a significant effect on technological advance and productivity increase in another organization in another country. For example, productivity increase in the American chemical industry was certainly influenced by the work of Ziegler in Germany and of Natta in Italy.

To shed new light on the process of international technology transfer, we have carried out several types of studies. One study was concerned with the channels of international technology transfer and the effects of international technology transfer on U.S. R & D expenditures. Another study was concerned with the size and characteristics of overseas R & D carried out by U.S.-based firms. Still another study dealt with the transfer of technology by U.S.-based firms to their overseas subsidiaries.[9] Based on these studies, it seems that economists should reconsider some of the models that have been used most frequently to represent the process of international technology transfer.

The traditional way of viewing the process of international technology transfer has been built around the concept of the product life cycle.[10] According to the product life cycle, a fairly definite sequence exists in the relationship between technology and trade, whereby the United States tends to pioneer in the development of new products, enjoying for a time a virtual monopoly. After an innovation occurs, the innovator services foreign markets through exports, according to this model. As the technology matures and foreign markets develop, companies begin building plants overseas, and U.S. exports may be displaced by production of foreign subsidiaries. The concept of the product life cycle has had a great influence in recent decades because it has been able to explain the train of events in many industries.

At least four of our findings seem relevant in this regard. First, our data suggest that the situation may be changing, that the product life cycle may be less valid than in the past. By the mid-1970s, in the bulk of the cases we studied, the principal channel through which new technologies were exploited abroad during the first five years after their commercialization was foreign subsidiaries, not exports (see table 6.4). About 75 percent of the technologies transferred by U.S. firms to their subsidiaries in developed countries during 1969–78 were less than five years old.

9. See Mansfield, Romeo, and Wagner (1979); Mansfield, Teece, and Romeo (1979); Mansfield and Romeo (1980).

10. Vernon (1966, 1970).

Table 6.4 Percentage Distribution of R & D Projects, by Anticipated Channel of International Technology Transfer, First Five Years after Commercialization, Twenty-Three Firms, 1974

	Channel of Technology Transfer				
	Foreign Subsidiary	Exports	Licensing	Joint Venture	Total[a]
All R & D projects[b]	74	15	9	2	100
Projects aimed at:[c]					
Entirely new product	72	4	24	0	100
Product improvement	69	9	23	0	100
Entirely new process	17	83	0	0	100
Process improvement	45	53	2	1	100

Source: See section 6.6.

[a]Because of rounding errors, percentages mat not sum to 100.

[b]This is the mean of the percentage for sixteen industrial firms and for seven major chemical firms. The results are much the same in the two subsamples. Only projects where foreign returns were expected to be of some importance (more than 10 percent of the total for the first subsample and 25 percent of the total for the second subsample) were included.

[c]Only the chemical subsample could be included.

Based on our data, the "export stage" of the product cycle has often been truncated and sometimes eliminated. Particularly for new products, firms frequently begin overseas production within one year of first U.S. introduction. In some industries, such as pharmaceuticals, new products commonly are introduced by U.S.-based firms more quickly in foreign markets than in the United States (in part because of regulatory considerations).

Second, there seems to be a difference in this regard between products and processes. For processes, the "export stage" continues to be important (table 6.4). Firms are more hesitant to send their process technology overseas than their product technology because they feel that the diffusion of process technology, once it goes abroad, is harder to control. In their view, it is much more difficult to determine whether foreign firms are illegally imitating a process than a product.

Third, to a large extent, this change in the process of international technology transfer and trade reflects the fact that many U.S.-based (and foreign-based) firms have come to take a worldwide view of their operations. Many of them now have in place extensive overseas manufacturing facilities. As indicated above, many also have substantial R & D activities located abroad. Given the existing worldwide network of facilities and people, firms are trying to optimize their overall operations. This may mean that some of the technology developed in the United States may find its *initial* application in a Canadian subsidiary, or that an innovation developed in its Canadian subsidiary may find its *initial* application in the firm's British subsidiary, and so on.

Fourth, the product life cycle is less valid than it used to be because technology is becoming increasingly internationalized. For example, in the pharmaceutical industry it is no longer true that a new drug is discovered, tested, and commercialized all within a single country. Instead, the discovery phase often involves collaboration among laboratories and researchers located in several different countries, even when they are within the same firm. And clinical testing generally becomes a multicountry project. Even in the later phases of drug development, such as dosage formulation, work often is done in more than one country. In contrast, the product life cycle seems to assume that innovations are carried out in a single country, generally the United States, and that the technology resides exclusively within that country for a considerable period after the innovation's initial commercial introduction.[11]

6.7 "Reverse" Technology Transfer

"Reverse" technology transfer is the transfer of technology from overseas subsidiaries to their U.S. parents. Some analysts tend to dismiss technology transfer of this sort as unimportant. Yet practically nothing is known about the extent and characteristics of "reverse" technology transfer, even though such information obviously would be of relevance to public policymakers concerned with the technological and other activities of multinational firms.

To determine the extent to which overseas R & D by U.S.-based firms has resulted in technologies that have been applied in the United States, we obtained data pertaining to twenty-nine overseas R & D laboratories of U.S. firms in the chemical, petroleum, machinery, electrical equipment, instruments, glass, and rubber industries. This sample of overseas laboratories, chosen essentially at random from those of major firms in these industries in the Northeast United States, accounts for about 10 percent of all overseas R & D spending by U.S.-based firms. The industrial and geographical distribution of the sample is reasonably similar to the industrial and geographical distribution of all overseas laboratories according to the National Science Foundation and other data sources.[12]

The following four findings help to put "reverse" technology transfer into better perspective. First, over 40 percent of these laboratories' 1979 R & D expenditures resulted in technologies that were transferred to the United States. Thus, such transfer is common and by no means insignificant. However, there are vast differences among overseas laboratories in

11. See Mansfield et al. (1982).
12. This work is being done with Anthony Romeo.

the percentage of R & D expenditures resulting in technologies transferred to the United States. Most of this variation can be explained by three factors: (1) whether the laboratory's primary function is to produce technology for worldwide application, rather than to service or adapt technology transferred from the United States or to produce technology for foreign aplication; (2) the laboratory's total R & D expenditures; and (3) the percentage of its total R & D expenditures devoted to research rather than development.

Second, there is a very short lag (on the average) between the date when a transferred technology first is applied abroad and the date when it is first applied in the United States. Indeed, in the electrical equipment firms in our sample the average lag is negative. Because of the size and richness of the American market, firms tend to introduce new products (and processes) based on technologies developed in their overseas laboratories about as quickly in the United States as in their overseas markets. These results indicate the extent to which firms take a global view of the introduction of innovations. As pointed out in section 6.6, this is a departure from the situation years ago.

Third, based on our data, more recently developed technology tends to be transferred more quickly to the United States than technology developed years ago. Also, technologies yielding relatively large profit in the United States were transferred more quickly than those that were less profitable here.

Fourth, although much of the R & D carried out overseas is directed at the adaptation and improvement of existing technology, overseas R & D laboratories have generated technology that was the basis for new products and other innovations that contributed billions of dollars in profits to U.S. manufacturing firms in 1980, if the laboratories in our sample are representative in this respect.

6.8 Overseas R & D and Productivity Growth of U.S. Firms

As pointed out in section 6.7, "reverse" technology transfer is not included (at least explicitly) in existing models of R & D and productivity growth. Indeed, because the official R & D statistics have excluded U.S. firms' overseas R & D expenditures until recently, previous studies of the relationship between a firm's or industry's R & D expenditure and its rate of productivity increase have ignored overseas R & D. Obviously, it would be interesting and useful to include U.S. firms' overseas R & D in such models and to see how much effect it has on the productivity growth of these firms.

To do this, it is convenient to use essentially the same model as that employed by Mansfield (1968, 1980), Griliches (1980), and Terleckyj (1974), except that research and development is disaggregated into two parts: domestic R & D and overseas R & D. In a particular firm, the production function is assumed to be:

$$(2) \qquad Q = Ae^{\lambda t} R_d^{\beta_1} R_o^{\beta_2} L^{\nu} K^{1-\nu},$$

where Q is the firm's value added, R_d is the firm's stock of domestic R & D capital, R_o is its stock of overseas R & D capital, L is its labor input, and K is its stock of physical capital. Thus, the annual rate of change of total factor productivity is

$$(3) \qquad \rho = \lambda + \theta_1 \frac{dR_d/dt}{Q} + \theta_2 \frac{dR_o/dt}{Q},$$

where $\theta_1 = \delta Q/\delta R_d$, and $\theta_2 = \delta Q/\delta R_o$. And based on the usual assumptions,[13]

$$(4) \qquad \rho = \lambda + a_1 \frac{X_d}{Q} + a_2 \frac{X_o}{Q},$$

where X_d is the firm's domestic R & D expenditures, and X_o is its overseas R & D expenditures in the relevant year.

My econometric results pertain to fifteen chemical and petroleum firms, for which I have estimated ρ for 1960–76 (see Mansfield 1980). For each of these firms I obtained data concerning X_d/Q and X_o/Q. The results are shown in table 6.5.[14] Estimates of a_1 and a_2 could be obtained by least squares,[15] the results being

$$(5) \qquad \begin{array}{l} \rho = 0.022 + 0.19 X_d/Q + 1.94 X_o/Q \cdot \\ \quad\;\; (7.40) \quad (2.44) \qquad\quad (1.90) \end{array}$$

These results have at least two implications. First, they indicate that overseas R & D, as well as domestic R & D, contributes to productivity growth of U.S. firms. The estimate of a_2 is positive and statistically significant. More surprisingly, the estimate of a_2 is much larger than that of a_1, indicating that a dollar's worth of overseas R & D had much more effect on productivity increase than a dollar's worth of domestic R & D. But this difference is not statistically significant. For most firms, I doubt that a_2 is this much larger than a_1, based on our other studies. But be this as it may, equation (5) certainly is consistent with our findings in section 6.7 concerning the nontrivial nature of "reverse" technology transfer.

13. These assumptions are described in detail in Mansfield (1980).

14. One firm included in Mansfield (1980) could not be included here because it is part of a foreign-based multinational firm. The data concerning X_d/Q and X_o/Q were obtained from the firms.

15. Tests were carried out to determine whether an industry dummy variable should be included in equation (5). The results provide no statistically significant evidence that this should be done.

Table 6.5 **Values of X_d/Q, and X_o/Q, Fifteen Chemical and Petroleum Firms**[a]

Firm	$\frac{X_d}{Q}$	$\frac{X_o}{Q}$
1	.0500	0
2	.0890	.0043
3	.0715	0
4	.0610	.0024
5	.0770	0
6	.0820	.0091
7	.0101	0
8	.0061	.0003
9	.0072	.0001
10	.0068	0
11	.0114	0
12	.0118	.0001
13	.0073	0
14	.0087	.0020
15	.0147	0

Source: See section 6.8.

[a]The data concerning X_d/Q and X_o/Q pertain to a year in the mid-1960s (1963–65). It was not possible to get data for precisely the same year, but the results should be sufficiently comparable for present purposes.

Second, these results allow a first glimpse of the nature of the bias that may have resulted from the omission of overseas R & D expenditures in some past studies. If X_o/Q had been omitted from equation (5), the result would have been

$$\rho = \underset{(6.61)}{0.022} + \underset{(3.95)}{0.28} X_d/Q. \qquad (6)$$

Thus, a_1 would have been higher than if both overseas and domestic R & D were included. In cases where Xo/Q has been positively correlated with Xd/Q, as in the present instance, the rate of return from domestic R & D may have been overestimated in previous studies, since a_1 has often been interpreted as such a rate of return.

6.9 Imitation Costs, Patents, and Market Structure

In the previous three sections we have been concerned with the transfer of technology from one nation to another, where the transferor and transferee are often parts of the same firm. Now let's return to technology transfer within the same nation, where the transferor and transferee are different firms, and where the transfer is involuntary from the point of view of the transferor. In particular, suppose that one firm imitates (legally) another firm's innovation. How much does it cost? How long does it take? How often does it occur? Economists have long recognized the importance of these questions. For example, they frequently have pointed out that, if firms can imitate an innovation at a cost that is substantially below the cost of developing an innovation, they may have little or no incentive to be innovative. Yet no attempts have been made to measure imitation costs, to test various hypotheses concerning the factors influencing those costs, or to estimate their effects.

To help fill this important gap, we obtained data from firms in the chemical, drug, electronics, and machinery industries concerning the cost and time of imitating (legally) forty-eight product innovations.[16] Imitation cost is defined to include all costs of developing and introducing the imitative product, including applied research, product specification, pilot plant or prototype construction, investment in plant and equipment, and manufacturing and marketing start-up. (If there was a patent on the innovation, the cost of inventing around it is included.) Imitation time is defined as the length of time elapsing from the beginning of the imitator's applied research (if there was any) on the imitative product to the date of its commercial introduction.

For present purposes, four findings of this study are of particular interest. First, innovators routinely introduce new products even though other firms can imitate these products at about two-thirds (often less) of the cost and time expended by the innovator. In our sample, imitation cost averages about 65 percent of innovation cost, and imitation time averages about 70 percent of innovation time. Considerable variation exists among products in the ratio of imitation cost to innovation cost. Much of this variation can be explained by differences in the proportion of innovation costs going for research, by whether an innovation was a drug subject to FDA regulations, and by whether an innovation consists of a new use for an existing material that is patented by another firm.

Second, the magnitude of imitation costs in a particular industry seems to have a considerable impact on the industry's market structure. How rapidly a particular innovation is imitated depends on the ratio of imitation cost to innovation cost. Also, an industry's concentration level tends to be low if its members' products and processes can be imitated easily and cheaply. The latter relationship is surprisingly close. Apparently, differences among industries in the technology transfer process (including transfers that are both voluntary and involuntary from the point of view of the innovator) may be able to explain much more of the interindustry variation in concentration levels than is generally assumed.

Third, in most cases, patents seem to have only a modest effect on imitation costs, as shown in table 6.6. However, in the drug industry, patents seem to have a bigger impact than in other industries. According to the firms, about one-half of the patented innovations in our sample

16. This work was done with Mark Schwartz and Samuel Wagner. Some of the results appear in Mansfield, Schwartz, and Wagner (1981).

Table 6.6 **Estimated Percentage Increase in Imitation Cost Due to Patents, Thirty-three New Products, Chemical, Drug, Electronics, and Machinery Industries[a]**

Percent Increase in Imitation Cost	Number of Products
Under 10	13
10–19	10
20–49	4
50–99	0
100–199	3
200 and over	3
Total	33

Source: See section 6.9.

[a]Not all innovations in our sample are included here because not all were patented or patentable.

would not have been introduced without patent protection. But the bulk of these innovations occurred in the drug industry. Excluding the drug industry, the lack of patent protection would have affected less than one-fourth of the patented innovations in the sample.

Fourth, patented innovations seem to be imitated surprisingly often and quickly. In our sample, about 60 percent were imitated within four years of their initial introduction. Reality seems to depart sharply from the commonly held belief that a patent holder is free from imitation for the life of the patent. In my view, it is very important that this fact be taken into account by the excellent economic theorists working in this area, since sometimes models of the innovation process tend to assume that the innovator receives all of the benefits from an innovation and that imitation can be ignored.

6.10 Innovation and Market Structure

In recent years, economic theorists have also begun to focus on the effects of innovation on market structure. Of course, technological change has long been recognized as one of the major forces influencing an industry's market structure. Karl Marx stressed this fact over a century ago. But the renewed interest is welcome, since traditional models of the relationship between innovation and market structure have been deficient in many respects.

Unfortunately, empirical findings on this score have also been relatively scanty. Little is known about the effects of recent major process innovations in various industries on the minimum efficient scale of plant. Almost nothing is known about the effects of recent major product innovations in various industries on the extent of concentration. To help fill this gap, I obtained information from twenty-four firms in the chemical, petroleum, steel, and drug industries about the effects of over sixty-five process and product innovations that were introduced in the past half-century.[17]

Although this study is still in a relatively early phase, several findings are emerging. First, in the chemical and petroleum industries, the bulk of the process innovations resulted in increases in miminum efficient scale of plant. In steel, only about half of the process innovations resulted in such increases, but most of the rest had little or no effect on minimum efficient scale. Thus, in all three industries,[18] scale-increasing innovations far outnumbered scale-decreasing innovations.[19] However, although relatively few major innovations in these industries have reduced minimum efficient scale, a substantial proportion have had no appreciable effect on it.

Second, the evidence of these industries does not support Blair's (1972) well-known hypothesis that, since World War II, fewer innovations tend to increase minimum efficient scale than in the past. To test this hypothesis, I compared the proportion of process innovations introduced after 1950 that resulted in such an increase with the proportion introduced before or during 1950 that did so. Contrary to Blair's hypothesis, the proportion was higher, not lower, in the later period.

Third, in all four industries combined, less than half of the product innovations in the sample seemed to increase the four-firm concentration ratio. The percentage was particularly low in drugs. The fact that only a minority of these major new products increased concentration in these industries is noteworthy, given the common tendency among economists to view technological change as a concentration-increasing force. If these industries are at all representative (and if this preliminary result holds up in my subsequent work), there should probably be more emphasis on innovation's role in reducing and limiting existing concentration.[20]

6.11 Conclusions

The findings presented here have a number of implications for public policy. With respect to government R & D policy, they suggest the following: (1) In their attempts to increase productivity, policymakers should recognize the importance of long-term R & D and basic research.

17. The lists of innovations came from Mansfield (1968), Mansfield et al. (1977), and Landau (1980).

18. The drug industry was excluded here because of its emphasis on product innovation.

19. This seems to be in accord with the observed changes in minimum efficient scale in these industries. See Scherer (1980).

20. In their paper on this subject, Nelson and Winter (1978) emphasize the concentration-increasing effects of innovation. However, they are careful to point out that their computer simulations represent a "partial view," not a "general model."

(2) Policymakers should also recognize that much of the apparent increase in real industrial R & D during 1969–79 (which was relatively modest in any event) may have been a statistical mirage, caused by the lack of better price indexes for R & D inputs. (3) Changes in federally financed R & D expenditures (at least in energy) are unlikely to be offset to any appreciable extent by changes in privately financed R & D ; on the contrary, such changes seem to induce changes in the same direction in privately financed R & D. (4)To the extent that policymakers want to increase the spillover from federally financed to privately supported R & D, the results suggest that firms should be encouraged to work with government agencies in the design of federally financed R & D projects.

With respect to patent policy, the findings seem to suggest that, except for pharmaceuticals and agricultural chemicals, patents frequently are not regarded as essential by innovators. Excluding drug innovations, more than three-fourths of the patented innovations in our sample would have been introduced without patent protection. In a minority of cases, patent protection had a very major effect on imitation costs and delayed entry significantly, but in most cases it had relatively little effect. Obviously, these findings have important implications concerning the patent system's role in stimulating technological change and innovation.

With regard to antitrust policy, our findings shed new light on the relationship between an industry's concentration level and the nature of its technological activities. Highly concentrated industries seem to devote a relatively low percentage of their R & D to basic research, and there is an inverse (but not significant) relationship between an industry's concentration ratio and the percentage of its R & D that is long-term or aimed at entirely new products and processes. Also, our results (covering the chemical, drug, petroleum, and steel industries) provide new information about the frequency with which major new products result in increases in concentration. In our sample, many new products (particularly in drugs) seem to have been introduced by firms that "invaded" the relevant market or that were not among the leaders in that market. This is not to argue that innovations do not frequently increase concentration. But it does suggest that the role of innovation in undermining existing concentration may sometimes be underestimated.

With respect to national policies concerning international technology transfer and the multinational firm, our findings underscore the extent to which technology is transferred across national boundaries, the difficulties and costs involved in trying to stem the technological outflow from U.S. firms to their foreign subsidiaries, and the benefits to the United States from the inflow of technology from these subsidiaries. "Reverse" technology flows are becoming increasingly important. Based on our econometric results, overseas R & D has a considerable effect (per dollar spent) on productivity of U.S. firms. These facts should be taken into account in the evaluation of the role of multinational firms in contributing to technological change and economic growth in the United States.

Our findings should also be of use to industrial managers. Faced with the difficult task of choosing an R & D portfolio, managers badly need evidence concerning the relationships between the composition of a firm's R & D expenditure, on the one hand, and its innovative output and rate of productivity increase, on the other. Also, they need more sophisticated and reliable indexes of the rate of inflation in R & D to budget their resources properly, and they can benefit from improved techniques for forecasting engineering employment.

Besides being of interest to policymakers, we believe that these findings have some implications for economic analysis. In my opinion, models relating R & D to productivity change should go further in disaggregating R & D, in taking account of international technology flows (and, in some cases, interindustry technology flows), and in using better R & D price indexes. For many purposes, it may also be useful to view government R & D as a factor that expands the profitability of private R & D. With regard to the role of technology in international trade, the product life cycle model should be altered or supplanted to recognize the changes that have occurred in this area. Further, students of industrial organization should devote more attention to the measurement and analysis of imitation costs (and time); this is a central concept that has been ignored entirely in econometric work.

In conclusion, the limitations of the studies described here should be noted. Although many of the samples (of firms, R & D projects, innovations, and so forth) are reasonably large, they nonetheless cover only certain industries or sectors of the economy. In many instances, the theoretical models we use are highly simplified. No pretense is made that the findings presented here are the last words on the subject. However, we believe that these findings increase our understanding of a wide variety of major topics about which relatively little (often, practically nothing) has been known.

References

Blair, John. 1972. *Economic concentration: Structure, behavior, and public policy*. New York: Harcourt Brace Jovanovich.

Brach, Peter, and Edwin Mansfield. 1982. Firms' forecasts of engineering employment. *Management Science* 28:156–60.

Goldberg, Lawrence. 1978. Federal policies affecting industrial research and development. Paper presented at the Southern Economic Association, November 9.

Griliches, Zvi. 1980. Returns to research and development expenditures in the private sector. In *New developments in productivity measurement and analysis*, ed. J. W. Kendrick and B. N. Vaccara, 419–54. Conference on Research in Income and Wealth: Studies in Income and Wealth, vol. 44. Chicago: University of Chicago Press for the National Bureau of Economic Research.

Jaffe, S. A. 1971. A price index for deflation of academic R & D expenditures. Washington, D.C.: NSF 72-310.

Landau, Ralph. 1980. Chemical industry research and development. *Innovation and U.S. research*, ed. W. N. Smith and Charles Larson. Washington, D.C.: American Chemical Society.

Levin, Richard. 1981. Toward an empirical model of schumpeterian competition. Working paper series A, no. 43. Yale School of Organization and Management.

Link, Albert. 1981. A disaggregated analysis of R and D spending. Paper presented at Middlebury College, April 17.

Mansfield, Edwin. 1968. *Industrial research and technological innovation: An econometric analysis.* New York: Norton for the Cowles Foundation for Research in Economics, Yale University.

———. 1980. Basic research and productivity increase in manufacturing. *American Economic Review* 70:863–73.

———. 1981a. Composition of R and D expenditures: Relationship to size of firm, concentration, and innovative output. *Review of Economics and Statistics* 63:610–15.

———. 1981b. How economists see R and D. *Harvard Business Review* 59: 98–106.

Mansfield, Edwin, and Anthony Romeo. 1980. Technology transfer to overseas subsidiaries by U.S.-based firms. *Quarterly Journal of Economics* 94:737–50.

Mansfield, Edwin, Anthony Romeo, and Lorne Switzer. 1981. R and D price indexes and real R and D expenditures. *Research Policy* 12:105–12.

Mansfield, Edwin, Anthony Romeo, and Samuel Wagner. 1979. Foreign trade and U.S. research and development. *Review of Economics and Statistics* 61:49–57.

Mansfield, Edwin, Mark Schwartz, and Samuel Wagner. 1981. Imitation costs and patents: An empirical study. *Economic Journal* 91:907–18.

Mansfield, Edwin, David Teece, and Anthony Romeo. 1979. Overseas research and development by U.S.-based firms. *Economica* 46:187–96.

Mansfield, Edwin, John Rapoport, Anthony Romeo, Edmund Villani, Samuel Wagner, and Frank Husic. 1977. *The production and application of new industrial technology*. New York: Norton.

Nelson, Richard, and Sidney Winter. 1978. Forces generating and limiting concentration under Schumpeterian competition. *Bell Journal of Economics* 9:524–48.

Scherer, F. M. 1980. *Industrial market structure and economic performance*. 2d ed. Chicago: Rand-McNally.
Terleckyj, Nestor. 1974. *Effects of R & D on the productivity growth of industries: An exploratory study*. Washington, D.C.: National Planning Association.
Terleckyj, Nestor, and David Levy. 1981. Factors determining capital formation, R and D investment, and productivity. Mimeo.
Vernon, Raymond. 1966. International investment and international trade in the product cycle. *Quarterly Journal of Economics*.
———, ed. 1970. *The technology factor in international trade*. New York: National Bureau of Economic Research.

Comment Zvi Griliches

I agree with Mansfield about the potential importance of good R & D deflators and I am glad to see him doing something about it. Some years ago (as part of my work with the Census-NSF data, see Griliches 1980), being in dire need of an R & D price index, I "constructed" one, patterning it on the methodology of Jaffe (1972). The resulting index is nothing but a weighted average (with almost equal weights) of the hourly compensation index and the implicit deflator in the nonfinancial corporations sector. This index has two advantages over the usual overall GNP deflator: (1) It is based on data from a more relevant subsector of the economy. (2) It gives wage rates more weight, which is as it should be since R & D is more labor intensive than the average corporate product. The resulting index is shown in table C6.1. On Mansfield's base 1969 = 1.00; my index was at 2.01 in 1979, compared to Mansfield's mean values in table 6.1 of 1.98, 2.01, and 2.00. I do not think one could come closer if one tried. This would seem to indicate that this type of a simple approximation may be pretty good, at least in recent years. Nevertheless, it would be desirable if NSF or BLS would take on the task of constructing and keeping up-to-date an actual price index such as Mansfield's.

Two additional brief notes: (1) Other attempts to construct an R & D price index were undertaken by Goldberg (1979), Schankerman (1979), and Halstead (1977). They all come out roughly in the same place: an R & D input price index rises by more than the GNP deflator. (2) We are considering here an R & D *input* price deflator. We have no data to attempt an R & D *output* price deflator. It is not clear whether the

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Table C6.1 **Approximate Deflator for R & D Expenditures (1972 = 1.00)**

1957	.598	1969	.855
1958	.616	1970	.906
1959	.631	1971	.956
1960	.647	1972	1.000
1961	.658	1973	1.064
1962	.670	1974	1.170
1963	.680	1975	1.285
1964	.698	1976	1.361
1965	.711	1977	1.459
1966	.737	1978	1.573
1967	.768	1979	1.7175
1968	.809	1980	1.870

Note: Index = .49 hourly compensation index + .51 implicit deflator, both for nonfinancial corporations. (Value of 1957 hourly compensation extrapolated using the hourly compensation figures for the manufacturing sector.) Underlying data from U.S. Department of Labor, *Productivity and Costs in Nonfinancial Corporations*, Washington, D.C., various issues.

"productivity" of R & D has been growing or diminishing over time. From a social point of view it could be growing. From the private point of view of a company or a university it has probably been declining, in the sense that to keep the same competitive edge, to stay in the same position in the commercial or academic market, R & D laboratories today need more expensive equipment, computers, and materials. From the point of view of a laboratory director his real "costs" of R & D are rising faster than is indicated by Mansfield's or my index.

References

Goldberg, L. 1979. The influence of federal R & D funding on the demand for and returns to industrial R & D. Alexandria, Va.: The Public Research Institute, October.

Griliches, Zvi. 1980. Returns to research and development expenditures in the private sector. In *New developments in productivity measurement and analysis*, ed. J. W. Kendrick and B. N. Vaccara, 419–54. Conference on Research in Income and Wealth: Studies in Income and Wealth, vol. 44. Chicago: University of Chicago Press for the National Bureau of Economic Research.

Halstead, Kent D. 1977. Higher education prices and price indexes, 1977 supplement. Washington, D.C.: National Institute of Education.

Jaffe, S. A. 1972. A price index for deflation of academic R & D expenditures. Washington, D.C.: NSF 72-310.

Schankerman, Mark. 1979. Essays on the economics of technical change: The determinants, rate of return, and productivity impact of research and development. Ph.D. diss., Harvard University.

Comment George C. Eads

Ed Mansfield's paper reflects the wide range of research he has conducted on the topics covered by this conference. Hardly a single area has failed at some time or another to attract his attention. Wherever he has chosen to work, we are the richer for his contribution.

While it would be possible to evaluate each of the pieces of research reported in this paper as an individual item, I believe it instructive to group them into categories. This enables us not only to assess the items' individual worth, but also to view Mansfield's research from a broader perspective. Although others might be suggested, I propose a two-fold divsion. The first division includes the works of what I will refer to as the "neoclassical" Mansfield; the second, the works of the "pragmatic" Mansfield. The "neoclassical" Mansfield is a member of a group of researchers who have attempted to apply neoclassical production functions to the measurement of the determinants of the growth of output (in his case, concentrating on the role that technological change plays in generating that growth). The "pragmatic" Mansfield is perhaps the leading exponent of an ad hoc approach to investigating the microeconomics of technological change. While his contributions in both areas have been considerable, it is the latter body of his research that I have found to be consistently the most provocative, raising questions about the way we ought to approach the study of technical change and forcing us to reexamine our preconceptions.

Indeed, it often performs such a role in the research of the "neoclassical" Mansfield. Consider section 6.2, "Composition of R & D: Effects and Determinants." Examination of the *American Economic Review* piece from which this section is drawn reveals that the results reported early in the section stem from the estimation of a neoclassical model based on a Cobb-Douglas production function. The dependent variable is value added by a given industry during period t. The independent variables are the industry's labor input, stock of physical capital, and two kinds of R & D capital—basic and applied. After performing suitable transformations and simplifications, Mansfield ends up with a single equation model which he estimates under various specifications.

The coefficient associated with the basic research variable is found to be consistently significant. The significance of this coefficient leads Mansfield to his principal conclusion: holding constant the amount an industry spends on *applied* R & D, the higher the proportion of research that is basic (or long-term), the higher the rate of productivity over the 1948–66 period. (Mansfield's attempts to replicate these results using data from the post-1966 period have proved unsuccessful.) Mansfield is well aware

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of the pitfalls in interpreting his results. In particular, the direction of casuality is ambiguous. (These problems and their implications are discussed in more detail in the *American Economic Review* piece.) Yet the finding, even qualified, is provocative.

But there is more, for the "pragmatic" Mansfield cannot resist having a crack at the topic that the "neoclassical" Mansfield has opened. Near the end of the *American Economic Review* piece (and in the third and fourth summary points in section 6.2 of the paper), Mansfield reports the results of arraying data he has collected concerning recent changes in the composition of industry R & D expenditures. (Since he is merely looking for interesting connections, he employs simple correlation analysis and some multiple regressions.) I find his conclusions provocative: that there is a critical distinction between *basic* (i.e., "long-term") research and what I would term "breakthrough" research—research aimed at relatively new products and processes. His results suggest that large firms do indeed perform a disproportionately large share of the *basic* research, but they perform a disproportionately *small* share of the "breakthrough" research. He also finds little if any statistical relationship between changes in the proportion of a firm's R & D expenditures directed to basic research and changes in the proportion directed to "breakthrough" research. Finally, he reports the various reasons cited by his survey respondents for recent declines in the amount of "breakthrough" research they fund.

At this point the section (and the *American Economic Review* piece) ends. I wish it hadn't, for I would have liked to have seen results reported in the latter part of the section related to those reported in the earlier part. A number of interesting questions suggest themselves. For example, "breakthrough" research would seem to be more amenable than basic research to targeted incentives relating to potential risk and reward. Both this logic and Mansfield's findings suggest that the two categories are likely to be affected quite differently by changes in underlying economic conditions—inflation and regulation, for example. But is one type of research more likely to generate important advances in productivity than the other? Are government policies designed to increase basic research a substitute for other policies designed to increase risk taking of the sort that leads to more "breakthrough" research?

This brings me to a more general point. Throughout the paper, Mansfield characterizes his research as "gap filling." Yet I inevitably finish a Mansfield study, especially one of the sort whose results are reported in section 6.2, more aware of what we *don't* know about technological change and more *dissatisfied* with our traditional approaches than convinced that a "gap" has somehow been closed. I don't want to be misunderstood. I yield to no one in my admiration of Mansfield's ability to collect interesting data, to array them in provocative ways, and to spin out interesting hypotheses about what they might imply. But let's be candid. Mansfield is *not* putting the finishing touches on a well-understood edifice called "The Economics of Technical Change." Instead he—and the rest of us—are laboring at a far earlier stage; one in which the surprises produced even by simple correlations might be enough to cause us to go back to our plans to see if we are even constructing the right structure. That Mansfield's work sends us back to the drawing board more often than it produces a feeling of satisfaction that a critical piece of the structure has been completed is not a criticism, therefore, but a comment on the relatively primitive state of our knowledge.

This gap *creating* tendency of much of Mansfield's research is illustrated by the sections of the paper that report on his excursion into the world of international R & D. Just when we were despairing at our inability to explain the causes of our nation's poor productivity performance using purely domestic variables, Mansfield suggests through his work that the problem might be even more complex than we had thought. For not only must we understand the connections between domestic variables, such as basic or applied R & D and the rate of technological change and, ultimately, the rate of economic growth; we must also take into account the flows of technology to and from the United States, especially between the overseas subsidiaries of U.S. firms and their domestic parents.

In section 6.6, Mansfield provides a framework for understanding the various types of international technology transfers. In section 6.7 Mansfield begins to explore the gains to U.S. technology from research performed overseas. In section 6.8 the "neoclassical" Mansfield again ventures forth. Using a model identical in structure to the one whose results are reported in section 6.2, he attempts to measure—albeit crudely—the contribution of research performed overseas to U.S. productivity performance for fifteen firms in the petroleum and chemical industries.

This time the R & D capital variable is divided not into "basic" and "applied," but into "domestic" and "overseas." The results by Mansfield's own admission are "surprising." Not only did overseas research contribute significantly to productivity for the firms in his sample, but the "bang for the buck" is nearly ten times as great. Mansfield dismisses this result since the two coefficients, though each significantly different from zero, are not significantly different from one another. I'm surprised at the model results in view of the fact that, according to table 6.5, eight of the fifteen firms for which Mansfield has data performed *no* overseas research at all during the period under investigation. The "bang" from the work of those that did certainly must have been powerful.

Mansfield then takes his model one step further. He attempts to derive an estimate of the possible "bias" from omitting the overseas research variable by comparing the domestic coefficient in the two-factor R & D model with one in which the overseas variable is excluded. The coefficient in the latter is larger than in the former, leading him to conclude that "the rate of return from domestic R & D may have been overestimated in previous studies"—including his, I presume. However, extreme caution is required in this interpretation because, by my calculations, the two coefficients are only marginally significantly different from each other.

The paper reports on several other interesting bits of research, mostly representative of the "pragmatic" Mansfield. For example, there is an attempt to measure the costs of imitation and, hence, the value of patents. The implication of this work is that, except in limited areas, patents provide surprisingly little protection to an inventor. The exception is the drug industry. Although Mansfield briefly refers to the potential impact of FDA regulations on his results, I'd like to know more about the possible interaction of FDA drug approval procedures and the efficacy of patents.

Another interesting tidbit is contained in section 6.4 where Mansfield attempts the analytically difficult task of separating out the effects of federal support of privately financed R & D. His research seems to imply an asymmetry. Each dollar's increase in federal R & D support generates only six cents additional private R & D during the first two years and then zero thereafter. But each dollar *cut* in federal R & D support causes a fall of twenty-five cents in private support during each of the first of two years and nineteen cents after the third year.

This and results reported later in the section suggest a finding contrary to that reported by Mansfield—namely, that federal R & D support exerts a growing, not a declining, influence over time on the character of a firm's R & D spending. If, as Mansfield contends, the federal influence declines, I'd be hard pressed to explain the asymmetry he observes. But again his results are preliminary, and we must await publication to examine his detailed argument.

Taken as a whole, this paper and the articles and books it refers to, both published and unpublished, reveal a highly productive research organization, led by an extraordinary individual, investigating a remarkable variety of interesting and important topics. The research methodologies employed by this organization are "problem driven," not "tool driven," and that is indeed fortunate. The nature of the problems they are investigating requires this. Indeed, it would be too bad if the "neoclassical" Mansfield ever prevailed decisively over the "pragmatic" Mansfield and imposed a rigid theoretical structure on the work of the University of Pennsylvania team. The research would be less useful and we would all be the losers.

Reply Edwin Mansfield

Given George Eads's generous comments concerning my paper and the research on which it is based, I feel no compulsion to take issue with him. It seems to me that our "neoclassical" and "pragmatic" work (if one accepts such a distinction) are linked together. Moreover, there clearly is a general model or theoretical framework on which all our empirical work is based. But he is quite right that this paper makes no attempt to put the pieces together. Having said this, I would like to clarify two small points. First, it is not quite true that attempts to replicate the results concerning the effects of basic research on productivity growth, using data from the post-1966 period, were unsuccessful. Although the fit is much poorer than in the pre-1966 period, the regression coefficient of the basic research variable is statistically significant in an appreciable number of specifications. Second, the apparent asymmetry in the effect of federal support on privately financed R & D may well be due to chance. The bigger apparent effect of a decrease than of an increase in federal support is attributable largely to a single firm in our sample. Although my paper pointed out that this apparent asymmetry should be viewed with considerable caution, I may have mislead Eads (and others) because my language was not stronger. Put bluntly, the apparent asymmetry may well be a fluke.

Turning to Zvi Griliches's comment on price indexes for R & D inputs, I think that the comparison he presents is interesting. Price indexes based on proxies are valuable, if they are reasonably accurate, since they are relatively cheap to construct. The Organization for Economic Cooperation and Development has also experimented with such indexes. In my view, actual price indexes should perhaps be combined with price indexes based on proxies. For example, actual price indexes might be constructed for benchmark years, and price indexes based on proxies might be used for interbenchmark years. I agree with Griliches that work should go forward to construct and compare both types of indexes. Moreover, it may well be that this work should be at the industry level, since there seem to be interindustry differences in the rate of increase of the price index for R & D inputs, a result apparently of interindustry differences in the types of R & D inputs used.