Research Policy 32 (2003) 1607–1617

research policy

www.elsevier.com/locate/econbase

# Edwin Mansfield's contributions to the economics of technology

Arthur M. Diamond Jr.*

*Department of Economics, University of Nebraska at Omaha, Omaha, NE 68182-0048, USA*

Received 2 April 1999; received in revised form 2 May 2002; accepted 27 January 2003

**Abstract**

Edwin Mansfield's contributions to the economics of technology are summarized from the early 1960s through his death in 1997. Mansfield's methodology is discussed, as are his contributions on: the diffusion of technical innovation, the effect of firm size on innovation, the role of academic and basic research in increasing innovation and productivity, international technology transfer and the inaccuracy of technological forecasts. The economics profession's evaluation of the relative importance of Mansfield's work is presented, using as evidence citation counts of his works collected from the *Social Science Citation Index* (SSCI). Identified as among Mansfield's most important contributions are his work on the importance of academic research for industrial innovations, his empirical estimation of the rates of diffusion of different innovations, and his estimation of the private and social returns from investments in industrial innovations. Finally, we present Mansfield's advice on the future of the economics of technology.



*Keywords:* Mansfield; Technology; R&D; Innovation; Diffusion

## 1. Mansfield's contribution

Edwin Mansfield was a widely respected source of practical knowledge on issues of crucial policy importance. He had the courage, some might say foolhardiness, to publish estimates on important policy issues, even when those estimates are subject to significant limitations.[1]

His contribution to economics was mainly in two areas: the economics of technology and the pedagogy of price theory. This paper focuses on technology, but it is worth mentioning that Mansfield's textbooks were widely adopted, highly cited, and effective in the classroom.

Current research in the New Growth Theory, both theoretical and empirical, increasingly implies that technological progress is *the* key engine of economic growth. If this is so, then the economics of technology has a claim to being one of the most important fields of economics.

* Tel.: +1-402-554-3657; fax: +1-402-554-2853.
*E-mail address:* adiamond@mail.unomaha.edu (A.M. Diamond Jr.).
*URL:* http://cba.unomaha.edu/faculty/adiamond/web/diahompg.htm.

[1] In late February 1997, Neal Lane, Director of the NSF, made use of the research of Edwin Mansfield to justify government funding of science, saying (Lane, 1998) that Mansfield "... found that government support lays the foundation for successful industry–university collaborations." Less than 2 months later, Kealey, Cambridge clinical biochemist and author of *The Economic Laws of Scientific Research* (Kealey, 1996) made use of the research of Edwin Mansfield to justify *ending* government funding of science, writing (Kealey, 1999) that Mansfield found that "... some 97 percent of commercially useful industrial technological development is, in practice, generated by in-house R&D." This episode may illustrate Stigler's dictum that whether you are a firefighter or an incendiary, you still need to know how fire works.

0048-7333/$ – see front matter 
doi:10.1016/S0048-7333(03)00056-8

Many trace the founding of the economics of technology to the work of Joseph Schumpeter.[2] But the field achieved prominence, definition and depth with the work of a more recent generation of "founding fathers." Who to identify in this way might be a matter of discussion, but on anyone's short list would be Edwin Mansfield.[3] Mansfield's general standing in the profession has been attested to by Medoff (1996, p. 49) who found that Mansfield had received the 26th highest number of citations from 1971 to 1992 among non-Nobel Prize-winning economists younger than 70 years of age. More specifically in the field of economics of technology, Granstrand (1994, p. 22) found that Mansfield was the most highly cited author in each of the four years examined (1976, 1984, 1991, and 1992). Arrow (2000, p. 2) is surely right that Mansfield "... has been a dominant figure in shaping our vision of the economics of innovation, a dominance based on very solid empirical and theoretical work."

With Mansfield's passing on November 17, 1997, it is appropriate to honor his contributions by reviewing them. But summarizing the contributions is no mere exercise in hagiography. Since he dealt with issues crucial to the technology policies of firms, universities and governments, reminding ourselves of what he learned, and how he learned it, may prove beneficial to the effort toward continued progress in this field.

Although almost all of Mansfield's important contributions appeared first in journal articles, he also published several monograph volumes that either made these articles more accessible, or else presented them in more extended form. Mansfield's monographs of this sort include: *Industrial Research and Technological Innovation: An Econometric Analysis* (1968); *New Research and Innovation in the Modern Corporation* (1971) (with Rapoport, Schnee, et al.); *The Production and Application of New Industrial Technology* (1977) (with Rapoport, Romeo, et al.); and *Technology Transfer, Productivity and Economic Policy* (1982) (with Romeo, et al.). In addition, Mansfield published two early volumes that summarized the state of knowledge in the economics of technology. The first, *The Economics of Technological Change* (1968) was intended for an academic audience, while the second, *Technological Change: An Introduction to a Vital Area of Modern Economics* (1971) was intended as a non-technical introduction to the subject.

In 1995, near the end of his career, Mansfield (1995) edited a two-volume collection of those of his articles that he considered most important, *Innovation, Technology and the Economy*, which also included an introductory essay in volume I that provides a useful summary of Mansfield's view of his own contributions, and of the state of knowledge on important issues as of 1995. For the rest of this paper, we will use "1995, I" to indicate this essay.

In the following sections of the paper, we discuss Mansfield's contributions in his 12 most highly cited articles,[4] as well as a few of his other articles in which he reached important or intriguing conclusions. Omitted from the following discussion are Mansfield's 6th and 11th most highly cited articles since they are aimed at communicating important results from the economics of technology to important groups of practitioners, specifically to scientists in the sixth ranked paper[5] and to business executives in the 11th ranked paper.

When citation rankings are mentioned in the following discussion, the reference is to the ranking based on 5-year citation counts. Table 1 provides a citation ranking of Mansfield's top 20 articles, while Table 2 provides a ranking of the six monographs on technology he published between 1968 and 1982 (see above). Appendix A discusses the method of obtaining the counts, and compares the citation ranking with Mansfield's own judgment of which of his articles

[2] Mansfield himself credits Schumpeter with founding the field (1995, I, p. ix). Rosenberg has gone so far as to say: "... the study of technological innovation ... still consists of a series of footnotes upon Schumpeter" (Rosenberg, 1982, p. 106). Granstrand notes that "J. Schumpeter is without doubt the father of the field in terms of citation appearance and influence upon others, as is widely acknowledged" (Granstrand, 1994, p. 19).

[3] As far back as 1970, Nadiri (1970, p. 1148) identified those who were beginning to study "... the theoretical aspects of endogenously determined technical changes." His list consisted of: Schmookler, Nordhaus, K. Shell, Arrow, Mansfield and Nelson.

[4] The choice of a cutoff point is somewhat arbitrary. We chose 12, because the author of this paper, as well as Mansfield himself, judged the 12th most cited article to have made a substantial contribution.

[5] Mansfield believed (1995, I, p. xiv) that his sixth ranked paper, "Contribution of R&D to economic growth in the United States" (1972) was used by both major branches of the federal government to set research priorities on the crucial question of how technology effects economic growth.

Table 1
Citations to articles

| Rank (5 years) | Rank (total) | Article | 5-year cites | Total cites | Reference |
|---|---|---|---|---|---|
| 1 | 10 | Academic research and industrial innovation | 45 | 48 | *Mansfield (1991) |
| 2 | 5 | Basic research and productivity increase in manufacturing | 41 | 100 | *Mansfield (1980) |
| 3 | 1 | Technical change and the rate of imitation | 28 | 335 | a,*Mansfield (1961) |
| 4 | 12 | Patents and innovation: an empirical study | 22 | 45 | *Mansfield (1986a) |
| 5 | 6 | Size of firm, market structure, and innovation | 20 | 87 | *Mansfield (1963b) |
| 6 | 16 | Contribution of R&D to economic growth in the United States | 20 | 39 | *Mansfield (1972) |
| 7 | 3 | Social and private rates of return from industrial innovations | 19 | 117 | a,*Mansfield et al. (1977b) |
| 8 | 8 | The speed of response of firms to new techniques | 19 | 61 | *Mansfield (1963c) |
| 9 | 17 | Industrial R&D in Japan and the United States: a comparative study | 17 | 37 | *Mansfield (1988b) |
| 10 | 11 | The speed and cost of industrial innovation in Japan and the United States: external vs. internal technology | 16 | 46 | *Mansfield (1988c) |
| 11 | 20 | How economists see R&D | 16 | 30 | Mansfield (1981b) |
| 12 | 4 | Imitation costs and patents: an empirical study | 15 | 106 | a,*Mansfield et al. (1981) |
| 13 | 9 | Organizational and strategic factors associated with probabilities of success in industrial R&D | 15 | 55 | *Mansfield and Samuel (1975) |
| 14 | 7 | How rapidly does new industrial technology leak out? | 14 | 67 | *Mansfield (1985) |
| 15 | 21 | Foreign trade and US research and development | 14 | 29 | *Mansfield et al. (1979a) |
| 16 | 2 | Entry, Gibrat's law, innovation, and the growth of firms | 13 | 147 | *Mansfield (1962) |
| 17 | 13 | Industrial research and development expenditures: determinants, prospects, and relation to size of firm and inventive output | 13 | 42 | Mansfield (1964) |
| 18 | 24 | Industrial innovation in Japan and the United States | 13 | 24 | Mansfield (1988a) |
| 19 | 18 | Intrafirm rates of diffusion of an innovation | 11 | 36 | *Mansfield (1963a) |
| 20 | 23 | Overseas research and development by US-based firms | 10 | 27 | *Mansfield et al. (1979b) |

[a] Article was included in the 1993 collection *The Economics of Technical Change* edited by Mansfield and Mansfield.
* Article was included in the two-volume collection of articles *Innovation, Technology and the Economy*.

Table 2
Citations to technology monographs

| Rank (5 years) | Rank (total) | Technology monograph | 5-year cites | Total cites | Reference |
|---|---|---|---|---|---|
| 1 | 2 | The Economics of Technological Change | 73 | 308 | Mansfield (1968b) |
| 2 | 1 | Industrial Research and Technological Innovation: An Econometric Analysis | 72 | 435 | Mansfield (1968a) |
| 3 | 3 | Research and Innovation in the Modern Corporation | 51 | 194 | Mansfield et al. (1971) |
| 4 | 4 | The Production and Application of New Industrial Technology | 42 | 145 | Mansfield et al. (1977a) |
| 5 | 5 | Technology Transfer, Productivity and Economic Policy | 29 | 62 | Mansfield et al. (1982) |
| 6 | 6 | Technological Change: An Introduction to a Vital Area of Modern Economics | 13 | 31 | Mansfield (1971) |

mattered most, as measured primarily by which articles he chose to include in his two 1995 volumes of his collected works.

## 2. The contribution of basic and academic research to innovation and productivity

In the final decade of his life, one of Mansfield's primary research focuses was on the role of academic research in promoting technological change. Throughout his career, Mansfield had been interested in the issue of the relationship of science and basic research to technological change. On the basis of many cases, Mansfield (*The Economics of Technological Change*, 1968) concluded that until the middle of the 1800s, the relationship between science and technology was loose. Mansfield claims (p. 44) that during earlier periods "on balance, science was far more indebted to technology than technology was to science." But with the growth of commercial laboratories at the end of the 1800s, the relationship became closer, with science more frequently leading the way.

Much later in his career (1991) Mansfield surveyed 76 large firms in seven manufacturing industries to see how many of their product and process innovations introduced in 1975–1985 could not have been made without academic science research performed in the 15 years before the innovation. The results are reported in Mansfield's most highly cited paper, which is entitled "Academic research and industrial innovation" (1991). For products, he finds that on average for the seven industries, 11% of the new products could not have been developed without recent academic research. The variation between industries is substantial, ranging from a low of 1% in the oil industry to a high of 27% in the drug industry. The average time lag between the academic research and the industrial innovation is about 7 years. In this paper, Mansfield estimates[6] the social rate of return to academic research as 28% (p. 11), while in a brief 1992 extension of the paper, he estimates it to be 40% (Mansfield, 1992, p. 296).

Because Mansfield recognized that not all innovations are of equal economic value, he proceeded to measure the sales attributed to each innovation. Although 11% of new innovations could not have been achieved without recent academic research, he finds that when the innovations are weighted by revenue, only 3% of the total revenue from new innovations could not have been achieved without substantial delay in the absence of recent academic research. It is interesting that in the body of the paper and in the conclusions of the paper, the 11% figure more congenial to the case for government funding is emphasized, rather than the more economically significant 3% figure that is reported in the table without other comment.

In his second most highly cited paper,[7] "Basic Research and Productivity Increase in Manufacturing," the key result is that the effect of basic research on a firm or industry's total factor productivity is not only positive, but actually larger than the effect of the same expenditure on applied R&D. In this 1980 paper, he also found that over the 1970s most industries in the US had reduced both the percent of their R&D that went to basic research and the percent of their R&D that went to projects identified as risky.

## 3. Adoption, diffusion, and transfer of new technologies

Mansfield's (1961) earliest major contribution to the economics of technology is his third most cited paper: "Technical change and the rate of imitation." In research complementary to Griliches (1957), Mansfield showed that similar s-shaped adoption processes existed for 12 innovations in several industries. His most striking finding in this area is to confirm that the speed of diffusion is positively related to the profitability of adoption.[8] Less strongly, he presents evidence suggesting that innovation diffuses more rapidly in less concentrated industries. This is a result that he would strengthen and confirm in later studies (e.g. the 1977 monograph, p. 208).

---

[6] Mansfield was one of the first economists to have estimated the social rate of return to academic research. He writes (1995, I, p. xviii) that his 1991 paper "Academic Research and Industrial Innovation" was used by the Bush administration to strengthen the case for federal support of academic research.

[7] Mansfield believed (1995, I, p. xi) that this paper had also influenced public science policy.

[8] Mansfield was also a leader in identifying some of the other determinants of differences in speed of adoption including the age and education of managers.

Mansfield's (1963c) eighth most cited paper was another early paper he published on the economics of adoption of new technologies, this one entitled "The speed of response of firms to new techniques." Mansfield finds that smaller firms adopt new technologies more slowly, and that more profitable technologies are adopted faster. Another important finding is that, holding firm size and profitability constant, early adoption of one technology is not a very good predictor that a firm will also be an early adopter of later technologies.

In his 12th most highly cited article, Mansfield and co-authors Schwartz and Wagner, find that imitating another firm's innovation costs about 65% of what the innovating firm spent to initially develop the innovation, and that within 4 years of the issuance of a patent, about 60% of the patented innovations had been imitated. This paper was one of only three of his own papers that Mansfield chose to include in the 1993 volume he edited on *The Economics of Technical Change* (Mansfield and Mansfield, 1993).

An important extension of Mansfield's work on the diffusion of technology is his research on international technology transfer. Some of this research was relevant to important policy debates, such as whether US firms' R&D activities abroad provided foreign firms a competitive advantage to US firms. In a 1984 paper with Romeo, Mansfield finds that significant new technology flows from US subsidiaries abroad to the US, a process they describe as a "reverse" transfer of technology. Much of Mansfield's work on technology transfer prior to 1986, including the important work in his 1982 monograph, is summarized in his paper "Technological change and the international diffusion of technology: a survey of findings" (Mansfield, 1986b). In this paper, Mansfield reports his finding of an increase in the rate of cross-country technology transfer, and that countries that invest more in R&D, are quicker at adopting other countries' innovations.

## 4. Patents and intellectual property rights

Mansfield's fourth most cited paper is "Patents and innovation: an empirical study" (Mansfield, 1986a) in which he uses survey data to test the Schumpeterian hypothesis that patents provide an important incentive for firms to innovate. Mansfield finds, to the contrary, that in most industries, firm respondents report that nearly all of the innovations achieved would still have been introduced even if there was no patent protection. Two industries were exceptions to the rule: pharmaceuticals and chemicals. A possibly paradoxical finding is that even in industries where patents are reported to be unimportant to innovation, most patentable innovations are still patented. (One might interpret this as support for the dictum that economists should attend to what agents *do*, not what they *say* about what they do.) A final important result in the paper is that there was no evidence of a decline in the 1970s of the propensity to patent, as had sometimes been alleged as an explanation for the decline in patents. Specifically, Mansfield found that from the 1965–1969 period to the 1980–1982 period, there was no decline in the percent of inventions that firms patented. This was an important finding (see Griliches, 1990, p. 1699) that increased the usefulness of patent data as a measure of inventive activity.

Secrecy is an alternative to patenting as a means to protect intellectual property. A significant finding of the Mansfield (1985) paper, "How rapidly does new industrial technology leak out?" is that information about new innovations "leaks" out within 12–18 months. Dosi (1988, p. 1131) suggests, however, that it takes significantly longer for the news to translate into the production or replication of the innovation.

In a later paper (Mansfield, 1993) on "Unauthorized use of intellectual property," Mansfield found that countries that protected intellectual property, ceteris paribus, received more (and higher quality) foreign investment.[9] These findings remain controversial. For example, using an index based on characteristics of countries' patent laws, Edson Kondo (1995a,b), found no relationship between the level of protection and the level of foreign direct investments. Mansfield's study was based on survey responses of US firms involved in foreign direct investment, while Kondo's was based on written laws. Mansfield's data could be criticized as subjective, while Kondo's data could be criticized for not measuring the level of enforcement of laws on the books, and for not distinguishing different

[9] I heard Mansfield speak eloquently on this topic to an international gathering of scientometricians at which he and I were the only economists—the audience was quite angry, but he firmly and politely refused to give an inch. (This occurred at the Fifth Biennial Conference of the International Society for Scientometrics and Infometrics in River Forest, Illinois in June 1995).

components of foreign direct investment. The latter may be important because one of Mansfield's most striking results was that the protection of intellectual property rights had the most effect on a firm's decision to invest in a particularly high quality component of foreign direct investment, namely investment in the research and development facilities in a country.

## 5. Firm size and market concentration

In his fifth most cited paper, Mansfield tests the well-known Schumpeterian hypothesis that large firms are more likely to produce innovations than small firms. In his paper "Size of firm, market structure, and innovation," Mansfield (1963b) finds that in the bituminous coal and petroleum refining industries, the four largest firms had a larger share of innovations, than they did of the market, but that in the steel industry the opposite was true. The optimal size firm for innovation was slightly smaller than the size of the four largest in the bituminous coal and petroleum refining industries, and much smaller in the steel industry. He concludes that the four largest firms are most likely to account for a large part of the industry innovations when innovation requires substantial capital, when firms need to be fairly large to make use of the innovations, and when the average size of the four largest firms was substantially larger than the average size of a firm in the industry.

In his 1964 *JPE* paper on "Industrial research and development expenditures ...," Mansfield finds that the four largest firms in the drug, glass and petroleum industries, invested a smaller percent of their revenues on R&D, than did somewhat smaller firms. In the steel industry, the difference was in the same direction, but was not statistically significant.

In his final major research on the subject, his 1981 "Composition of R&D expenditures ..." Mansfield studied 108 firms, classified into 12 industries (Mansfield, 1981a). At the firm level, he found (p. 611) that within an industry, "... increases in size of firm are associated with more than proportional increases in the amount spent on basic research." But he also found (p. 612) that the largest firms "... tend to carry out a disproportionately small share of the R&D aimed at entirely new products and processes." Also there was no relationship between firm size and the riskiness of R&D projects undertaken. At the industry level, he found (p. 612) that "the relationship between an industry's concentration level and its R&D spending is rather weak." Moreover, more concentrated industries devoted a smaller percentage of their R&D expenditures to basic research.

In a brief 1983 *AER* paper on "Technological change and market structure ... " Mansfield (1983) reports the interesting finding that there is no systematic relationship between technological change and a change in the level of concentration in the industry: some technologies increase concentration and some decrease it.

## 6. Social and private returns to firm innovation

In the seventh most cited paper (1977) Mansfield and several co-authors estimate the "Social and private rates of return from industrial innovations." The authors found a wide variation in the social rate of return, but usually found it to exceed 50%, often by a wide margin. Equally notable: the median social return was about twice the median private return. Specifically, they estimated that the median private rate of return was about 25% and the median social rate of return was about 56%. The paper remains a foundation for government technology policy to encourage firm R&D.

The credibility of the general finding was strengthened after being twice replicated by NSF-sponsored research. For the 20 innovations studied in the replication by Robert R. Nathan Associates, the median social rate of return was 70%, while the median private rate of return was 36% (Robert, 1978, p. 5, p. 7). For a different set of 20 innovations studied in the replication by Foster Associates, the median social rate of return was 99%, while the median private rate of return was 24% (Foster, 1978, p. iii). Scherer (1983) extended the Mansfield results to show that the difference between social and private returns increases linearly as social returns increase.

## 7. Japanese technological innovation

Mansfield's 9th and 10th most cited articles examine an issue of concern in the 1980s, the relative industrial strength of the Japanese versus the United

States economies. His "Industrial R&D in Japan and the United States: a comparative study" (1988) finds that Japan focused more on process innovations, as compared to the United States which focused more on product innovations. He also finds that the Japanese were efficient imitators and implementers of new technology, but did not have an advantage in performing basic research. His "The speed and cost of industrial innovation in Japan and the United States: external vs. internal technology" (1988) presents evidence on the relative time-costs in Japan and the United States for different types of innovation. He finds that Japanese firms have notably lower costs in imitating and exploiting technologies originally developed external to the firm. Mansfield viewed his research on Japanese innovation as a rough beginning of the investigation of inter-country differences: in reference to the difficulty of designing a survey instrument in a foreign language he was careful to note (p. 1167, footnote 26) that in this early research "… there is no way to eliminate completely the possibility of errors of interpretation by respondents."

## 8. The difficulty of technological forecasting

Mansfield argues, in his 1975 *Journal of Business* article with Wagner, that early investigation of the probability of success of projects increases their profit potential. Yet in one of the most significant findings of a 1971 paper with Schnee and Wagner, the authors present evidence that predictions from labs of the technical success of projects turned out to be only slightly more accurate than predictions based on chance. Similarly, in his 1978 *Journal of Business* article with Beardsley (Beardsley and Mansfield, 1978),[10] he also documents the poor quality of such forecasts of success, a problem he pessimistically attributes in 1995 to "inherent uncertainties" (p. xiii). A complementary finding in the 1971 paper was that cost overruns at two major pharmaceutical firms turned out to be of the same order of magnitude as those frequently found in defense contracting. These findings are not encouraging to policy makers, whether in the government or in the firm.

## 9. Mansfield's aims and method

For those who argue that personal tastes underlie a scholar's positions on important issues, Mansfield presents a difficult case to explain. On an affectionate, personal level, F.M. Scherer has noted[11] Mansfield's:

> … paradoxical aversion to modern technology. He didn't drive a car, flew only when there was no feasible rail alternative, didn't use credit cards, and didn't type. Once I was riding with him in a hotel elevator. He looked peaked. "Ed, is there something wrong?," I asked. "I never did like these elevators," he replied.

Mansfield, however, did not allow his personal technology aversions to distract him from his intellectual conclusions concerning the role that technological progress has played in economic growth.

Near the end of his career, Mansfield gave a clear summary and defense of the method that he applied in most of his research:

> In general, my approach has been to try to get a reasonably solid empirical footing before attempting to model complex phenomena about which very little is known; to keep the theoretical apparatus as simple, transparent and robust as possible; to collect data directly from firms (and other economic units) carefully tailored to shed light on the problem at hand (rather than to try to adapt readily available general-purpose data, which often is hazardous), and to check the results as thoroughly as possible with technologists, executives, government officials and others who are close to whatever phenomenon is being studied (Edwin Mansfield, "Introduction." Innovation, Technology and the Economy, vol. I, 1995, p. ix.).

Although Mansfield occasionally made use of broad, macro level data (e.g. in "Rates of return …", Mansfield, 1965, *AER*), he concluded from "consulting and other experience" that "a more micro project-by-project analysis" is "often more trustworthy" (1995, I, p. xi).

F.M. Scherer has elaborated[12] on what was a unique aspect of Mansfield's micro research:

[10] It is perhaps puzzling that the 1978 paper contains no mention to the 1974 paper.

[11] Personal communication from Scherer (2000).

[12] Personal communication from Scherer (2000).

What was remarkable about him was that he cultivated a large stable of R&D vice presidents he could ring up, and who were sufficiently loyal that they would go out of their way to answer his difficult questions. It really was unique; only Al Link comes close. The "data" he got were subjective, but they enormously illuminated what technological innovation was all about, despite qualms about subjectivity and inability to replicate.

Mansfield's method was primarily to apply econometric analysis to original data to answer important questions about technical change. While many economists appear to be indifferent to the policy relevance of their work, Mansfield clearly hoped that much of his work would provide a useful basis for business and government policy (1995, I, p. ix).

## 10. Mansfield's suggestions for the future

More important, perhaps, than specific suggestions[13] for future research, are Mansfield's general comments on the future promise of the economics of technology. One source of Mansfield's final advice comes near the end of a 1996 book review (Mansfield, 1996):

> Everyone seems to agree that technological change is at the heart of the process of economic growth. Over the past 40 years, progress has been made in understanding the economics of technological change. Based on empirical, historical, statistical, and theoretical studies by economists, a body of knowledge has been developed which has proved useful to firms and governments. ... But our understanding of diffusion, imitation, innovation, and development is much stronger and richer than our understanding of research and invention. Extraordinary creativity remains a mystery; no one can make dependable long term predictions of what inventions will occur and when, or of what their effects will be.
>
> While one can write down equations stating that inventive output depends on R&D (and other) inputs during the current and previous periods, such equations are unlikely to be very useful for purposes of long-run prediction; many firms and government agencies have engaged in long-term technological forecasting, with little success. This, of course, does not mean that economists should not study the long-term economic development of nations, and try to explain what has occurred. But it does mean that, whereas it may be possible to reproduce "stylized facts" from the past, the invention of models that can make useful long-term predictions is likely to be an elusive goal[14] ("Book review of Silverberg et al. ... ", 1996, pp. 180–181).

A second source of Mansfield's advice for the future is at the end of the introductory essay of his 1995 volumes of his collected works:

> (The economics of technological change) remains an area where there is a particular need for people who are comfortable working in, and drawing on, a variety of disciplines. Very few problems of any consequence can be solved within the confines of a single discipline. It continues to require persons who have a lively interest in both basic and applied work, and who are able to use each to enrich the other. It is still an area needing people who like to work on ill-defined problems where little is known and nothing is tidy, but where the rewards for even a partial solution are very high. Those with such attributes should be encouraged to enter this field because the opportunities continue to be enormous. While a lot more is known now than 40 years ago, the truth is that economists have only scratched the surface" (Edwin Mansfield, "Introduction." *Innovation, Technology and the Economy*, vol. I, 1995, p. xxi).

## Acknowledgements

I am grateful for substantial research assistance on this project from Haizhi Tong, Hui Wang and

---

[13] For example, Mansfield (1995, I, p. xviii) suggests that international technology flows need to be incorporated in models of productivity change.

[14] Mansfield elaborates the elusiveness of long-term technological predictions by citing an anecdote from Kenneth Arrow's wartime weather forecasting experiences. The conclusion of the anecdote is that for complex phenomena, the time it would take for prediction, exceeds the time it takes for the events to play out.

Xuecheng Wang. I have also received useful research assistance from Xenia Gonzales, Ke Yang, and Lei Wang. I am grateful to Janet Conway and Lucille Mansfield for sending me Professor Mansfield's curriculum vita and other useful materials. I have received extensive and valuable suggestions from F.M. Scherer and also benefited from the comments of an anonymous referee. A few sentences in the paper have already appeared in my (1996) review essay "The Economics of Science." An earlier version of the paper was presented at the 1999 meetings of the American Economic Association.

## Appendix A. Measuring Mansfield's contributions

In this paper, the aim has been to discuss Mansfield's most important contributions. In judging "importance" we make use of Mansfield's own judgments about what was important in his work, the judgments of other distinguished scholars in the field and the judgments implied by citation counts of Mansfield's publications.

One of the key sources of Mansfield's own judgments of what is most important in his work is the two-volume collection of his articles that he edited and published in 1995 under the title *Innovation, Technology and the Economy*. Using the same logic, the three of his own articles that Mansfield included in the 1993 volume he edited with Elizabeth Mansfield, *The Economics of Technical Change*, would pass an even higher standard of self-judged importance.

No review essays of Mansfield's life opus have yet appeared to serve as a source for the profession's views of the relative importance of Mansfield's contributions. In the absence of such sources, a useful proxy for such judgments is the number of times various works of Mansfield have been cited in the literature. Although skepticism is sometimes expressed on the usefulness of citation analysis, Mansfield himself believed that citations were a useful measure of academic productivity and intellectual influence.[15]

Our sources for citations are the various volumes from 1966–1997 of the *Social Science Citation Index* (*SSCI*). Rankings based on citations can only be viewed as rough measures of relative importance to the profession for a variety of well-known reasons that do not need to be fully rehearsed here. Since Mansfield's older publications have had more years in which to accumulate citations than his more recent writings, citations were counted for a 5-year period closely following the publication date of an article or monograph.[16] This "5-year" citation count was used to rank publications in Tables 1 and 2, although the "total" ranking is also presented, and is usually not much different from the "5-year" ranking. Table 1 lists the 20 most highly cited Mansfield articles, using the 5-year citation count. Table 2 lists citations to all of Mansfield's monographs (excluding textbooks and article collections).

Since the *SSCI* only lists citations under the first author of an article, it simplified the process of counting citations that Mansfield was either the sole author or the first author of all but six of his articles. We counted the citations for these six articles under their first author and found that none of the six ranked among his 20 most highly cited articles.

Some prominent economists (e.g. Joan Robinson and Sir John Hicks) in later years prominently disputed the profession's assessment of what was most important and valuable in their life work. So it may be useful to note how much Mansfield's assessment of his own work corresponds to the profession's.

The citation rankings in Tables 1 and 2 provide some important evidence of the profession's assessment. For Mansfield's self-assessment, we may find evidence in what he chose to include as editor of essay collections later in life. In 1995, he reprinted 44 of his articles in

[15] For example, in one of his summaries of his contributions, Mansfield mentions that he "... was among the 20 economists in the United States most cited in professional journals from 1971 to 1985" (Mansfield, 1997, p. 1).

[16] For articles published before 1966, the measure is the number of citations to the article in the 1966–1970 *SSCI* cumulative volume. For articles published from 1966 to 1970, the measure is the number of citations in the 1971–1975 *SSCI* cumulative volume. For articles published from 1971 to 1975, the measure is the number of citations in the 1976–1980 *SSCI* cumulative volume. For articles published from 1976 to 1980 the measure is the sum of the citations in the annual volumes from 1981 to 1985. For articles published from 1981 through 1991, the measure is the sum of the citations in the annual volumes for the 5 years immediately following the year of publication.

a two-volume set published under the title *Innovation, Technology and the Economy*.

In 1993, along with Elizabeth Mansfield, he published 25 essays by himself and by others under the title *The Economics of Technical Change*. Of these 25 essays, 3 were either solely authored or co-authored by Mansfield (#3, #7, and #12 in Table 1).

Of the 20 most highly cited Mansfield articles listed in Table 1 of this paper, all but 3 were reprinted among the 44 articles in the 1995 volumes. (The 17 reprinted articles, among the top 20 cited articles, are each indicated by an asterisk in Table 1.) Of the three excluded, two (#11 and #18) could be viewed as non-specialist summaries of work that appeared in more detail elsewhere. A more puzzling omission (#17) is the Mansfield (1964) *JPE* paper on industrial research and development. This article constituted the second (and core) chapter of Mansfield's highly cited 1968 monograph *Industrial Research and Technological Innovation*. Perhaps Mansfield believed that the availability of the material in that book, reduced the marginal value of including the 1964 article in the collected works volume.

The three Mansfield articles that pass the more selective self-assessment screen of inclusion in the 1993 volume, rank in the top 12 by the profession's assessment, using the "5-year" counts, and in the top *four* by the "total" counts. Thus, Mansfield's own judgments of which of his works were important does not seem much different from the profession's.

As a possible, partial exception to this generalization, we should note that in the 1995 book, of the 10 topics to which Mansfield thought he had made significant contributions, the articles on two topics were not highly cited by the profession. Specifically, none of the four articles on "Public Policy Towards Civilian Technology" and none of the four articles on "Technological Forecasting" were among Mansfield's 20 most cited articles.

## References


Arrow, K.J., 2000. Preface: Edwin Mansfield's research on technology and innovation. International Journal of Technology Management 19 (1–2), 1–2.

Beardsley, G., Mansfield, E., 1978. A note on the accuracy of industrial forecasts of the profitability of new products and processes. The Journal of Business 51 (1), 127–135.

Diamond Jr., A.M., 1996. The economics of science. Knowledge and Policy 9 (2–3), 6–49.

Dosi, G., 1988. Sources, procedures, and microeconomic effects of innovation. Journal of Economic Literature 26 (3), 1120–1171.

Foster Associates Inc., 1978. Final Report: A Survey on Net Rates of Return on Innovations, vol. 2, Summary and Analysis. An Economic Study for the National Science Foundation, Contract NSF-76-22518, May 1978.

Granstrand, O., 1994. Economics of technology—an introduction and overview of a developing field. In: Granstrand, O. (Ed.), Economics of Technology. North-Holland, Amsterdam, Chapter 1, pp. 1–36.

Griliches, Z., 1957. Hybrid corn: an exploration in the economics of technological change. Econometrica 25 (4), 501–522.

Griliches, Z., 1990. Patent statistics as economic indicators: a survey. Journal of Economic Literature 28 (4), 1661–1707.

Kealey, T., 1996. The Economic Laws of Scientific Research. St. Martin's Press Inc., New York.

Kealey, T., 1999. End Government Science Funding (Online available: http://www.cato.org/dailys/4-11-97.html), downloaded January 1, 1999.

Kondo, E.K., 1995a. The effect of patent protection on foreign direct investment. Journal of World Trade 29 (6), 97–122.

Kondo, E.K., 1995b. Patent Laws and Foreign Direct Investment: An Empirical Investigation. Doctoral Dissertation, Harvard University, May 1994.

Lane, N., 1998. Federal Priorities: Optimizing R&D Budget Resources (Online available: http://www.nsf.gov/od/lpa/forum/lane/nl97uc.htm), downloaded April 15, 1998.

Mansfield, E., 1961. Technical change and the rate of imitation. Econometrica 29 (4), 741–766.

Mansfield, E., 1962. Entry, Gibrat's law, innovation, and the growth of firms. The American Economic Review 52 (5), 1023–1051.

Mansfield, E., 1963a. Intrafirm rates of diffusion of an innovation. The Review of Economics and Statistics 45 (4), 348–359.

Mansfield, E., 1963b. Size of firm, market structure, and innovation. The Journal of Political Economy 71 (6), 556–576.

Mansfield, E., 1963c. The speed of response of firms to new techniques. The Quarterly Journal of Economics 77 (2), 290–311.

Mansfield, E., 1964. Industrial research and development expenditures: determinants, prospects, and relation to size of firm and inventive output. The Journal of Political Economy 72 (4), 319–340.

Mansfield, E., 1965. Rates of return from industrial research and development. The American Economic Review 55 (2), 310–322.

Mansfield, E., 1968a. Industrial Research and Technological Innovation: An Econometric Analysis. W.W. Norton & Company Inc., New York.

Mansfield, E., 1968b. The Economics of Technological Change. W.W. Norton & Company Inc., New York.

Mansfield, E., 1971. Technological Change: An Introduction to a Vital Area of Modern Economics. W.W. Norton & Company Inc., New York.

Mansfield, E., 1972. Contribution of R&D to economic growth in the United States. Science 175 (4021), 477–486.

Mansfield, E., 1980. Basic research and productivity increase in manufacturing. The American Economic Review 70 (5), 863–873.

Mansfield, E., 1981a. Composition of R&D expenditures: relationship to size of firm, concentration and innovative output. The Review of Economics and Statistics 63 (4), 610–615.

Mansfield, E., 1981b. How economists see R&D. Harvard Business Review 59 (6), 98–106.

Mansfield, E., 1983. Technological change and market structure: an empirical study. The American Economic Review 73 (2), 205–209.

Mansfield, E., 1985. How rapidly does new industrial technology leak out? The Journal of Industrial Economics 34 (2), 217–223.

Mansfield, E., 1986a. Patents and innovation: an empirical study. Management Science 32 (2), 173–181.

Mansfield, E., 1986b. Technological change and the international diffusion of technology: a survey of findings. In: McFetridge, D. (Ed.), Technological Change in Canadian Industry. University of Toronto Press, Toronto, pp. 77–99.

Mansfield, E., 1988a. Industrial innovation in Japan and the United States. Science 241, 1769–1774.

Mansfield, E., 1988b. Industrial R&D in Japan and the United States: a comparative study. The American Economic Review 78 (2), 223–228.

Mansfield, E., 1988c. The speed and cost of industrial innovation in Japan and the United States: external vs. internal technology. Management Science 34 (10), 1157–1168.

Mansfield, E., 1991. Academic research and industrial innovation. Research Policy 20 (1), 1–12.

Mansfield, E., 1992. Academic research and industrial innovation: a further note. Research Policy 21, 295–296.

Mansfield, E., 1993. Unauthorized use of intellectual property: effects on investment, technology transfer, and innovation. In: Wallerstein, M.B., Mogee, M.E., Schoen, R.A. (Eds.), Global Dimensions of Intellectual Property Rights in Science and Technology. National Academy Press, Washington, DC, pp. 107–145.

Mansfield, E., 1995. Innovation, Technology and the Economy: The Selected Essays of Edwin Mansfield, vols. I and II. Edward Elgar Publishing Limited, Brookfield, VT.

Mansfield, E., 1996. Book review of Silverberg, Gerald and Luc Soete. The economic of growth and technical change: technologies, nations, agents. Journal of Economic Literature 34 (1), 179–181.

Mansfield, E., 1997. Obituary. Last draft written by Edwin Mansfield (sometime after October 1, 1997).

Mansfield, E., Mansfield, E., 1993. The Economics of Technical Change. Edward Elgar Publishing Limited, Brookfield, VT.

Mansfield, E., Samuel, W., 1975. Organizational and strategic factors associated with probabilities of success in industrial R&D. The Journal of Business 48 (2), 179–198.

Mansfield, E., John, R., Jerome, S., Samuel, W., Michael, H., 1971. Research and Innovation in the Modern Corporation. W.W. Norton & Company, New York.

Mansfield, E., John, R., Anthony, R., Edmond, V., Samuel, W., Frank, H., 1977a. The Production and Application of New Industrial Technology. W.W. Norton & Company Inc., New York.

Mansfield, E., John, R., Anthony, R., Samuel, W., George, B., 1977b. Social and private rates of return from industrial innovations. The Quarterly Journal of Economics 91 (2), 221–240.

Mansfield, E., Anthony, R., Samuel, W., 1979a. Foreign trade and US research and development. The Review of Economics and Statistics 61 (1), 49–57.

Mansfield, E., David, T., Anthony, R., 1979b. Overseas research and development by US-based firms. Economica 46 (182), 187–196.

Mansfield, E., Mark, S., Samuel, W., 1981. Imitation costs and patents: an empirical study. The Economic Journal 91 (364), 907–918.

Mansfield, E., Anthony, R., Mark, S., David, T., Samuel, W., Peter, B., 1982. Technology Transfer, Productivity and Economic Policy. W.W. Norton & Company Inc., New York.

Medoff, M., 1996. A citation-based analysis of economists and economics programs. The American Economist 40 (1), 46–59.

Nadiri, M.I., 1970. Some approaches to the theory and measurement of total factor productivity: a survey. Journal of Economic Literature 8 (4), 1137–1177.

Robert, R., 1978. Net Rates of Return on Innovations, Executive Summary. An Economic Study for the National Science Foundation. Nathan Associates Inc., Contract NSF-76-22519, October 1978.

Rosenberg, N., 1982. Inside the Black Box: Technology and Economics. Cambridge University Press, New York.

Scherer, F.M., 1983. R&D and declining productivity growth. The American Economic Review 73 (2), 215–218.