

Industry
Trends
in
Research
Support
and
Links
to
Public
Research



National Science Foundation

National Science Board

Industry Trends in Research Support and Links to Public Research

The National Science Board (NSB) is charged with monitoring the health of the nation's science and engineering enterprise and advising the President and Congress on policy matters pertaining to research and education in the sciences and engineering. The release of the new edition of our biennial report, *Science & Engineering Indicators – 1998 (S&EI98)*,¹ provides the Board with an opportunity to note and comment on selected findings and trends of particular interest in the development of national policy.

Two important findings documented in *S&EI98* involve the capability of U.S. industry to develop new products and processes. The first is embodied in dual funding trends: namely, a restoration of funding by U.S. industry of its own research—representing a turnaround from the cutbacks that began in the late 1980s—in tandem with its continued—albeit relatively small—investment in basic and applied research at universities and colleges.

The second finding, based on a relatively new analytic technique, suggests that patents granted in the U.S. patent system are increasingly linked to public research.² Specifically, inventors in five industrial nations, including the United States, are increasingly taking advantage of the results of research performed in universities, government laboratories, medical schools, and nonprofit organizations. This is especially true in areas where the rate of new startup firms is high, such as biotechnology and pharmaceuticals. When American inventors cite research journal articles, the cited articles are overwhelmingly those produced by U.S. authors.

Clearly, both industrial investment in research and industrial use of publicly funded research have been growing. Thus, investments by industry and government continue to complement each other, with public investment—primarily in basic research—often serving as a precursor to private sector investment in many areas of applied research and development. Federal investment thereby continues to provide a critical seedbed for economic growth and for overall growth in job opportunities.

Highlights of these findings and for related indicators are presented below, followed by the Board's comments. Technical details are appended.

Highlights

Funding Indicators

- ◆ In constant-dollar terms, the amount invested by U.S. industry in its own basic research efforts dropped by a

fifth from 1991 through 1995,³ decreasing from \$6.3 billion to about \$5 billion. This investment began to rise in 1996 and is projected to continue rising by 1997 to an estimated \$6.5 billion in current dollars, or \$5.7 billion in constant dollars.

- ◆ Similarly, industry financing of its own applied research decreased by about 16 percent from 1991 through 1994, but is projected to be up by 37 percent in real terms by 1997 to an estimated \$28.6 billion in current dollars.
- ◆ U.S. industry's investment in basic research performed at U.S. universities and colleges increased in real terms by 20 percent from 1991 to 1997, rising to a total of \$1.05 billion in 1997 dollars. This represents about 6.5 percent of all academic basic research expenditures.

Citation and Authorship Indicators

- ◆ In their application to the U.S. Patent and Trademark Office, inventors must cite all “prior art”—that is, the previous patents as well as the other sources of information on which the present application is based. Most citations are to prior patents, but an increasing number of applications cite one or more research journal articles: in 1996, 25 percent of all assigned patents, and 29 percent of those from American inventors, did so. Analyzing the geographic, institutional, and funding sources of these cited articles in granted patents provides insight into the linkages between published research and new industrial developments.
- ◆ Analyses of the U.S.-granted patents that cited research papers suggest that the linkage between patents and public research was strengthening at an increasing rate across five major industrialized nations. This was particularly true for the half of U.S. patents granted to U.S. inventors. These overwhelmingly cited U.S.-authored research papers, two-thirds of which were published by organizations primarily supported by public funding. More recent data show a continuing acceleration in this general trend in citation linkage.
- ◆ The linkage is particularly evident in patents for “drugs and medicines.” Applications in this category cited, on average, several times the number of research papers cited, for example, in the category of “communication equipment and electronic components.”
- ◆ To the degree that cited research papers represent the science base for industry, U.S. industrial inventors tend to draw on U.S. public research for much of that base, ranging from 30 percent of their science citations from patents in “communication equipment and electrical components” to 50 percent in “drugs and medicines.” As a point of comparison, U.S. inventors relied on U.S. industry

¹ Ordering information for *Science & Engineering Indicators 1998* (NSB 98-1) appears at the end of this paper; the report is also available on the World Wide Web <<<http://www.nsf.gov/sbe/srs/stats.htm>>>.

² Public research refers here to research performed in academic, nonprofit, and government research organizations that is in the public domain. In the United States such research is primarily funded by the Federal Government.

³ Due to revisions in survey methodology, data prior to 1991 may not be strictly comparable to data for years after 1991.

research much less frequently; only about 17 percent of science citations in “drugs and medicines” patents were to U.S. industry research papers.

- ◆ The number of journal articles published each year by U.S. industrial researchers in physical science fields declined sharply during the 1990s, and has been dropping in engineering and technology since the 1980s. Concurrently, research publication activity has continued to climb in biotechnology and medicine. These trends may in part reflect restructuring and refocusing of corporate R&D.
- ◆ Coauthorship of journal articles by U.S. industrial researchers with either academic or Federal researchers increased steadily across all fields from 1981 to 1995.

Commentary

The Board welcomes the rebound in company investment in their own research efforts. In our view, part of this increase reflects a realization by some firms that had reduced investments earlier that, to remain highly competitive, they should begin to rebuild their research capabilities. The prevailing economic conditions of the past few years facilitated such investment opportunities.

The Board also welcomes the continuing trend by companies to increase their investments in basic and applied research performed in academic institutions. Such research is closely linked to the education of scientists, engineers, and technical workers; and companies often invest in it to be closer to a potential source of talented students as well as to keep abreast of the latest developments in their fields of interest. The transfer of research findings to technological advances is often facilitated when recent graduates take jobs in industry.

Though growing, industrial investment in basic academic research is still relatively small, amounting to about one-fifteenth of the nation’s total investment in academic basic research. The roles of industrial and Federal investment are, of course, complementary. The Federal Government funds research to meet its own missions or to benefit the public as a whole; this includes providing funding where individual firms are not likely to invest because they would not be able to “capture” the resulting benefits. Therefore, traditionally, funding of academic basic research has been the role of the Federal Government rather than that of industry.

The analysis of patent citations to research journal articles is a relatively new technique, developed to provide a window on the relationship between research findings and industrial innovation. While most patent citations are to previous patents, the growing incidence of citations to research papers indicates the increasing importance of publicly funded research to U.S. industry—particularly in areas such as biotechnology and pharmaceuticals. The impact of publicly

funded scientific research on the national economy is realized when companies use such patents to introduce new products or services into the marketplace or to make their manufacturing or service processes more effective.

Clearly, both industrial investment in research and industrial use of publicly funded research have been growing. Thus, investments by industry and government continue to complement each other, with public investment—primarily in basic research—often serving as a precursor to private sector investment in many areas of applied research and development. Federal investment thereby continues to provide a critical seedbed for economic growth and for overall growth in job opportunities.

Appendix Indicator Descriptions and Detailed Findings

Funding Indicators

Industrial Investment in Company-Performed Research Is Beginning to Be Restored

Several prominent companies reduced the size and redirected the focus of their central research facilities in the late 1980s and early 1990s; the proportion of corporate research funding in the budgets of decentralized business units was decreased as well. These declines show up as drops in company funding of both basic and applied research.

From 1991 through 1995, companies’ investment in their own performance of basic research declined more than a fifth, in constant-dollar terms, dropping from \$6.3 billion to \$5 billion. Surveys of industry reveal that such investment is projected to increase by 15 percent between 1995 and 1997 in constant dollars, rising to an estimated \$6.5 billion in current dollars.

Similarly, industrial expenditures for companies’ own applied research dropped 16 percent in constant dollars from 1991 to 1994; however, this investment is projected to increase 37 percent (in constant dollars) after 1994, reaching \$28.6 billion in current dollars in 1997.

Industrial Investment in University Research up 20 Percent Since 1991 to \$1.5 Billion

Industrial investment in basic and applied research performed at universities and colleges is estimated to have risen 20 percent (in constant dollars) between 1991 and 1997. Industrial firms accounted for an estimated 6.5 percent of all academic basic research expenditures and 9.1 percent of all academic applied research expenditures, amounting to \$1.05 billion and \$545 million, respectively.

Percent of citations from 1993 & 1994 U.S. Industrial patents to research papers, by origin of paper

| Product field | U.S. public research | U.S. industry research | Non-U.S. research |
|---|----------------------|------------------------|-------------------|
| Drugs & medicines | 50 | 17 | 33 |
| Chemicals | 43 | 18 | 39 |
| Communication equipment & electronic components | 30 | 37 | 33 |

Citation and Authorship Indicators

Public Research Papers⁴ Are Increasingly Cited in Patent Applications

Applications for U.S. patents include citations to important prior patents and to other sources of information, including published research articles. On average, 7 percent of the references cited in 1993 and 1994 were to such articles. Research citations varied greatly among industrial product fields: for example, patents granted to U.S. firms in the “drugs and medicines” category cited an average of 6.4 research references per patent, while the average number of references cited in the “chemicals” category was 1.7, and the average for those in the “communication equipment and electronic components” product field category was 0.4.

To the degree that cited papers represent the science base of patents, U.S. firms patenting in the three major U.S. industrial sectors mentioned above produced 17 to 37 percent of the papers they cited in 1993 and 1994 patents, and depend to a considerable degree on public research conducted in the United States. (See table above.)

Techniques for analyzing the linkage between newly granted patents and cited articles have been developed over the past decade to give policymakers and policy researchers a new window into the process of invention and innovation.⁵ Such techniques underestimate the actual amount of linkage between patents and articles, because each analytic step is based on conservative data selection methods. Thus, articles not in the relevant time frames, or not in the database of roughly 4,000 of the world’s most influential scientific and technical journals,⁶ are not counted; also, counts

include only citations on the front page of issued patents, whether placed there by applicants or patent examiners, but not citations within the patents’ texts.

Comparisons were made between two periods: patents granted in 1987 and 1988, citing papers from 1975 to 1985 (period 1), and patents granted in 1993 and 1994, citing papers from 1981 to 1991 (period 2). The linkage between U.S. patents granted in period 2 to inventors in all countries and U.S.-authored research papers was dramatically greater than the linkage in period 1. The number of papers cited more than doubled, and the number of citations to those papers almost tripled, rising from 16,600 in period 1 to 49,500 in period 2. By comparison, between 1987 and 1994 (the years covered by the two periods), the number of patents granted increased by 28 percent, and the number of papers in the journal database increased by 16 percent.

The trend is occurring across a broadening base of patents. The fraction of all patents granted by the United States that cited at least one scientific paper increased dramatically between 1985 and 1995—from 11 percent to 23 percent. The effect was more pronounced for high-technology areas. For example, the proportion of “drugs and medicines” patents citing at least one paper grew from 45 to 76 percent, while the proportion in the “other chemical” category almost doubled, increasing from 25 to 47 percent.

Recent information from a second, related data set which used slightly different periods of citation years shows that the linkage increased even more rapidly in the latest period. In this data set, the number of citations in 1995 and 1996 patents to U.S.-authored papers published in the previous 10 years jumped by about half again to 79,500. Due to technical factors, this figure is not precisely comparable to the period 1 and 2 data discussed above, but does confirm the strength and direction of the trend.

Analysis of U.S. patents granted to inventors in the five countries leading in patent activity (the United States, Japan, Germany, United Kingdom, and France) shows that linkages to industry are stronger for papers in clinical medicine and biomedical research than in other fields. Citations from U.S.-granted patents to papers in those fields are increasing quickly for inventors in all five countries, but fastest for U.S. and U.K. inventors.

The linkage time between citations from patents to the scientific literature for patents in the “drugs and medicines” category was relatively short: the peak year for papers cited was four to six years earlier than the patent, which is only a year or two slower than citation patterns among biomedical research articles.

American Inventors Overwhelmingly Cite U.S.-Produced Research Papers

Analysis of the half of U.S. patents granted to U.S. inventors (in the period 1/period 2 data set) reveals the following:

- ◆ U.S. inventors overwhelmingly cited papers produced by U.S. authors. For example, papers that acknowledged

⁴ Public research refers here to research performed in academic, non-profit, and government research organizations that is in the public domain. In the United States such research is primarily funded by the Federal Government.

⁵ Francis Narin, Kimberly S. Hamilton, and Dominic Olivastro, “The Increasing Linkage Between U.S. Technology and Public Science,” *Research Policy* 26, No. 3 (December 1997): 317-30.

⁶ The set covered by the Science Citation Index published by the Institute for Scientific Information.

funding by the National Science Foundation were cited in five times as many patents having at least one U.S. inventor as in patents granted to foreign inventors only.

- ◆ Half of the cited papers produced in the United States and cited by U.S. firms were authored by researchers in American colleges, universities, and medical schools; almost a third were written by industry scientists; and most of the rest were by researchers at the National Institutes of Health, the federally funded research and development laboratories of the Department of Energy and the National Aeronautics and Space Administration, and other government and not-for-profit organizations.
- ◆ The research underlying the papers produced in Federal and academic laboratories was largely supported by Federal funds, and the papers were published in prestigious, mainstream scientific and technical journals.

Industry Coauthorship of Journal Articles Has Doubled Since 1981

The proportion of industry-produced articles that were coauthored with at least one U.S. academic researcher increased from 21.6 percent in 1981 to 40.8 percent in 1995. The number of such articles in the 4,000-journal set more than doubled, rising from 2,905 to 7,479 articles.

Although increases in the number of coauthorships were evident in all fields, they were steeper in biomedical research than in five other categories analyzed: engineering and technology, biology, chemistry, physics, and mathematics. For example, 276—or 35.3 percent—of industrial articles in biomedical research had at least one university coauthor in 1981. By 1995, the number of coauthored articles had quadrupled to 1,216, or 44.1 percent of that field's total articles.

The number of articles authored by at least one U.S. industrial researcher and at least one researcher at a Federal agency or federally funded research and development center nearly tripled between 1981 and 1995, rising from approximately 800 to about 2,400. Also, the percentage of articles produced by such collaborations doubled, rising from about 6 percent to more than 12 percent of all industrial research papers. The fields that experienced the greatest growth in this type of collaboration were physics and earth and space sciences.

Number of Journal Articles in Engineering and Physical Sciences by U.S. Industrial Researchers Dropped Sharply While Those in Medical Research Increased

Researchers in U.S. industry wrote about 8 percent of the 142,800 U.S.-authored articles published in the 4,000-journal set in 1995. This percentage was about the same as in 1981, but during that time the nature of industrial research publishing changed dramatically. During the 1980s, the number of industry publications in engineering and technology fields dropped steeply. In the first half of the 1990s, that number continued to decline and was accompanied by declines in industrial publications in physics, chemistry, and mathematics. Over the same period, industry articles in clinical medicine doubled and those in biomedical research tripled; these two fields accounted for 40 percent of the industrial sector's total publications in 1995, compared with 19 percent in 1981.

Additional Reading

Colin McIlwain, "Industrial Research Booms in U.S., Despite Job Cuts at Large Labs," *Nature* 391, No. 669 (February 19, 1998): 723.

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William J. Broad, "Study Finds Public Science Is Pillar of Industry," *New York Times* May 13, 1997: C-1.

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