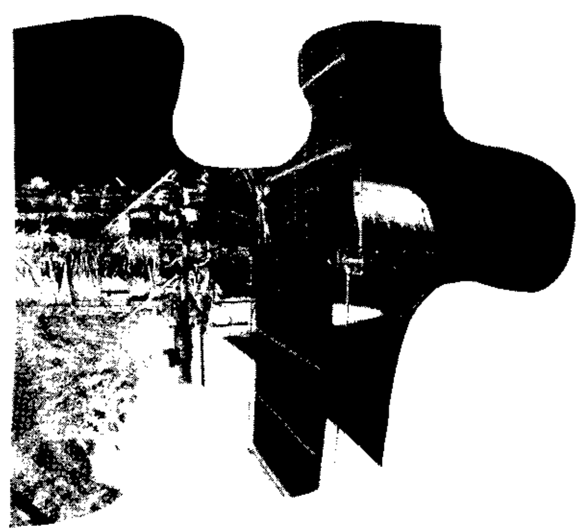
CHAPTER 2

The Value of Science and the Changing Research Economy



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Boxes

The Value of Science and the Changing Research Economy

This is a golden age of scientific discovery with great potential to improve our performance as a Nation. This is the rationale we use in our requests for increased funding. But even a country as rich as the United States cannot write a blank check for science. We need to discipline ourselves in how we request support and in how much we ask for. Otherwise we will lose our credibility.

Frank Press[1]

Introduction

Research advances the world stock of scientific knowledge and the countries that finance its pursuit. The United States, in particular, has a history of strong support of research and belief in its inherent worth. Scientific discoveries have spurred technological and other kinds of developments since the beginning of the industrial age, and thus have shaped much of Western culture. Cures to diseases have been found, better automobiles and space probes have been developed, the Earth and its environments more fully understood, and the foundations of atomic matter explored.

The importance of science to progress in most Western societies is indisputable. In the words of two economic historians:

> Science. . . is pushing back the frontiers of knowledge at what seems an accelerating pace. Because knowledge creates economic resources and because knowledge generally grows at an exponential rate, future advances in human welfare can be at least as striking as those of the past two hundred years.[2]

In the United States, scientific and engineering research has a significant impact on the products and processes that fuel U.S. economic growth and productivity.[3] There is also ample recognition of the significant role played by the Federal Government in legitimizing and financing research as a public good.[4] (This is epitomized by the case of superconductivity, see box 2-A.) Such findings are reassuring that, in the words of science policy statesman

1 "NAS Annual Meeting: Kudos From George Bush, Challenges From Frank Press," *NewsReport of the National Research Council,* vol. 40, June 1990, p. 8.

2 Nathan Rosenberg and L.E. Birdzell, Jr., "Science, Technology and the Western Miracle," *Scientific American,* vol. 263, No. 5, November 1990, p. 54.

3 Reporting the results of a new empirical investigation economist Edwin Mansfield finds: ". . . that about one-tenth of the new products and processes commercialized during 1975-85 in. . . [seven] industries could not have been developed (without substantial delay) without recent academic research, The average time lag between the conclusion of the relevant academic research and the first commercial introduction of the innovations based on this research was about seven years. . . . A very tentative estimate of the social rate of return from academic research during 1975-78 is 28 percent, a figure that is based on crude (but seemingly conservative) calculations and that is presented only for exploratory and discussion purposes. It is important that this figure be treated with proper caution. . . . Our results . . . indicate that, without recent academic research, there would have been a substantial reduction in social benefits." See Edwin Mansfield, "The Social Rate of Return From Academic Research," *Research Policy,* forthcoming 1991.

Another analysis, using different measures, supplements Mansfield's finding. While knowledge is found to be a major contributor to productivity growth, there is roughly a 20-year lag between the appearance of research in the academic community and its effect on productivity as measured by industry-absorbed knowledge. See James D. Adams, "Fundamental Stocks of Knowledge and Productivity Growth," *Journal of Political Economy,* vol. 98, No. 4, 1990, pp. 673-702. Of course, during the 20-year gestation period, much applied research and development must occur before the effects on industrial productivity are realized. Economists find Mansfield's empirical approach the most direct evidence of economic returns to date. Summary of reactions at American Economic Association and National Science Foundation seminars in 1989 and 1990 provided by Leonard hale- personal communication, January 1991. For a discussion of measurement techniques, see ch. 8.

4 Indeed, the U.S. research system is designed so that returns on Federal investment will accrue to the private SeCtor and other nations. The results of publicly funded research are for the most part openly disseminated with little or no copyright protection or patent exclusivity. For how this situation is changing, see U.S. Congress, Office of Technology Assessment, *Intellectual Property Rights in an Age of Electronics and information,* OTA-CIT-302 (Washington DC: U.S. Government Printing Office, April 1986). Also see Congressional Budget Office, "Federal Investment in Intangible Assets: Research and Development," unpublished document, February 1991.

Box 2-A—History of Superconductivity: Scientific Progress Then and Now

The history of superconductivity illustrates the episodic nature of progress in scientific research and the limitations of predictions for scientific advancement in a specific research area. Due to resistance, normal conductors will lose energy in the form of light or heat when a current is passed through them. While this is not a wholly undesirable effect (e.g., in heaters and light bulbs), in most electric applications, resistance wastes energy. Successfully harnessing the resistance-free currents of superconductors could be revolutionary: energy could be transmitted with perfect efficiency; electronic devices could be made faster and smaller; and the power of superconducting magnets (many of which are much stronger than traditional electromagnets) could transform traditional transportation methods both on land and at sea.[1] The first superconductor was discovered in 1911 by Kammerlingh Onnes, a Dutch scientist. Using liquid helium, Onnes cooled mercury to 4 degrees Kelvin (K) above absolute zero,[2] at which point an electric current flowing through the mercury suddenly lost all resistance (for a chronology of subsequent progress, see figure 2A-l).

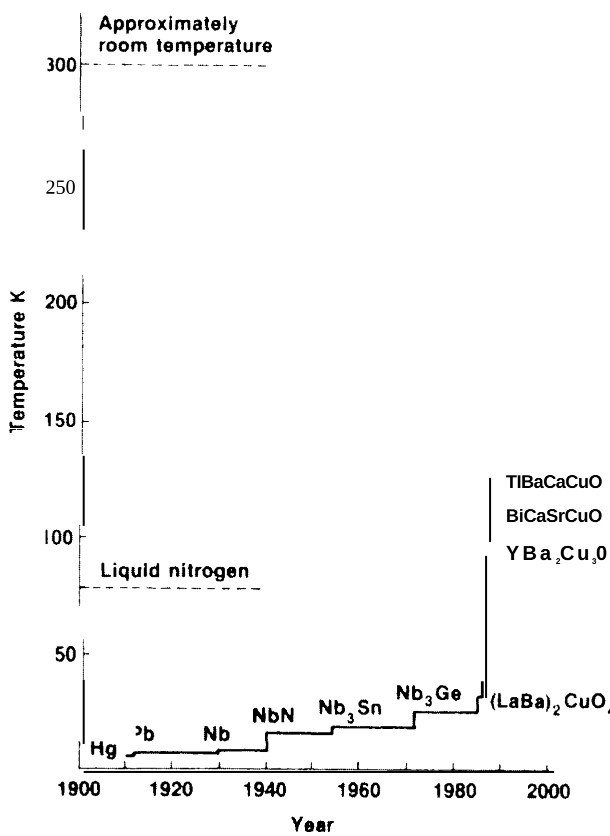
The Science of Superconducting Materials

Limitations on the physical properties required for a material to superconduct have hindered widespread applications. For every superconducting material there is a threshold for its physical properties (temperature, magnetic field level, and current density) above which it will not superconduct, By the 1950s, researchers had discovered many materials that would superconduct, but at temperatures no higher than about 20 K.

The 1950s brought two separate breakthroughs that moved superconductivity closer to applicability, First, researchers in the Soviet Union discovered a new class of superconductors that would remain superconducting in high magnetic fields, and that could eventually be used in superconducting magnets. Second, in 1957, the American research team of Bardeen, Cooper, and Schreiffer received the Nobel prize and recognition for a theory explaining superconductivity.

From the 1950s to the early 1980s, progress toward higher temperature superconductors was slow. Then, a surprising breakthrough occurred in late 1986 that transformed superconductivity research and drew widespread public attention. In Zurich, the IBM research team of Bednorz and Mueller discovered a new ceramic material that remained superconducting at temperatures as high as 35 K. A few months later in 1987, a research team at the University of Houston developed a similar ceramic material that could superconduct at 92 K. Not only did these discoveries provide the long-awaited ability to use liquid nitrogen instead of helium as a coolant, the discoveries were made at such an' incredible pace, considering the history of superconductivity research, that the goal of room-temperature superconductivity (at roughly 300 K) suddenly appeared to be within reach.

Figure 2A-l-Superconducting Critical Transition Temperature v. Year



SOURCE: U.S. Congress, Office of Technology Assessment, *High-Temperature Superconductivity in Perspective*, OTA-E-440 (Washington, DC: U.S. Government Printing Office, April 1990), figure 2-3.

[1] For a more comprehensive description of applications for superconductivity see U.S. -, Office of Technology Assessment, *High-Temperature Superconductivity in Perspective*, OTA-E-440 (Washington, DC: U.S. Government Printing Office, April 1990).

[2] One degree Kelvin (K) is equal to one de&w Celsius (°C), except that Kelvin is measured from absolute zero (-273 °C). Room temperature (about 75 'F, or 25 °C) is about 300 K.

The Federal Response

The response to these discoveries was enormous. The popular press lauded high-temperature superconductivity as ". . . the startling breakthrough that could change our world. Scientific meetings where superconductivity results were rumored to be released became standing-room-only events.[4] While the temperature barrier still frustrates researchers, work continues in other areas that are key to useful applications of superconductivity, like current densities and magnetic fields. Success has been attained in many areas, but much more research needs to be done.

Fortunately, the Federal Government has maintained its commitment: in 1987, President Reagan presented an 11-point agenda to increase superconductivity research and development (R&D) in the United States, and in 1988, Congress enacted several laws pertaining to superconductivity R&D, mostly aimed at spurring commercial development of superconducting technologies. The Federal superconductivity budget rose from $85 million in fiscal year 1987 to $228 million in fiscal year 1990, with most of the increase going to high-temperature research.[5] Funding is spread among several different agencies, primarily the Departments of Defense (DOD), Energy, and Commerce, the National Science Foundation, and the National Aeronautics and Space Administration. Programs at different Federal agencies have aided scientists in the exchange of research information.[6]

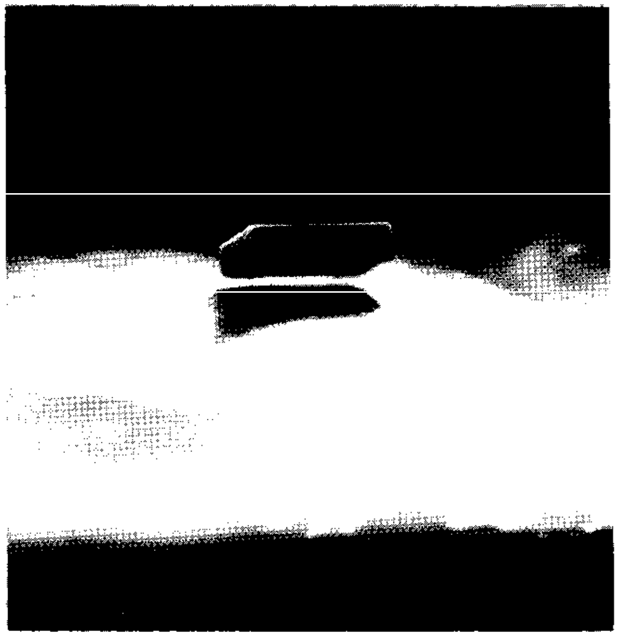


Photo credit: U.S. Department of Energy

A magnet is levitated by high-temperature superconducting materials that **are cooled in liquid nitrogen. Superconducting materials may eventually levitate much larger bodies, such as magnetically levitated trains. Superconductivity is a research area that may yield many fruitful applications.**

Congress has made several attempts to coordinate superconductivity research. Part of the 1988 Omnibus Trade and Competitiveness Act created the National Commission on Superconductivity (NCS). The Trade Act also mandated an increase in staff for the National Critical Materials Council (NCMC). Finally, the National Superconductivity and Competitiveness Act of 1988 called for cooperation among the Office of Science and Technology Policy (OSTP), NCMC, and NCS in order to produce a 5-year National Action Plan for Superconductivity to be accompanied by annual reports. The success of these initiatives has been limited. The 5-year National Action Plan was published in December of 1989, but the formation of NCS was delayed. Although the plan itself acknowledged the need for better Federal coordination, it lacked both the budget recommendations and the long-term perspective Congress had requested.[7] In addition, OSTP's Federal Coordinating Council on Science, Engineering, and Technology Committee on Superconductivity report of March 1989 did little more than assemble agency superconductivity budget data and list programs in the agencies.[8]

Questions remain, such as whether DOD funds too high a percentage of superconductivity research and whether the Federal laboratories are doing too much of the research relative to other performers. Progress in the development of high-temperature superconductivity is likely to unfold slowly—with substantial assistance from the Federal Government.

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[3] Michael D. Lemonick, "Superconductors!" *Time,* May 11, 1987, p. 64.

[4] Phil Adamsak "A Super Year in Science," *Visions,* fall 1987, p. 20.

[5] Office of Technology Assessment op. cit., footnote 1, p. *63.*

[6] The Arnes laboratory distributes the "High-T_c Update," a widely read newsletter, the national laboratories have broadcast nationally several high-temperature superconductivity conferences; and the Department of Energy has established a computer database that shares research results with industry. The National Aeronautics and Space Administration also maintains a Space Systems Technical Advisory Committee, a group with representatives from industry, universities, and government organizations.

[7] Office of Technology Assessment, op. cit., footnote 1, p. 63.

[8] Ibid., p. 69.

Harvey Brooks: "A strong basic science is a necessary condition for a strong economy, a livable environment, and a tolerable society. '

Survey results indicate that since the mid-1970s public confidence in the scientific community ranked second only to medicine and ahead of 11 other social institutions, including education, the press, and Congress.[6] Furthermore, the expectations of the American public about science and technology during the next 25 years include cures for cancer and AIDS, safe long-term storage or disposal of wastes from nuclear powerplants, establishment of a colony on the Moon, and development of genetically engineered bacteria to destroy toxic chemicals. But among the same sample of adults, realism about the possible negative consequences of science and technology is clearly evident. More than two in five respondents considered another Three Mile Island-type accident and the accidental release of a toxic chemical that results in numerous deaths of Ameri-Cans ''very likely. ' Finally, when asked their preference for problems that should receive more Federal funding, three of four Americans responded "helping older people," "improving education," and "reducing pollution, " two of three noted "improving health," one in two favored ''helping low income people," and one of three responded ''scientiilc research' (which was well ahead of ''exploring space' and 'improving defense' ').[8] For further discussion of Federal funding in the "public interest, see box 2-B.

Taken together, the investments and expectations of the Federal Government in research have contributed to a shining history of scientific advance in the United States. Universities, Federal laboratories, and industrial research centers have discovered many new phenomena and developed theories and techniques for their continued exploration and use. In the 1990s, preserving quality in research, while understanding changes in the political and economic environment in which it has grown, will require planning and adaptation by research sponsors and performers alike.

Research Funding in the United States

Focusing on research *(not* development), as OTA does in this report, reduces the scope, but not the complexity of the Federal research system.[9] The Federal Government spent over $11 billion in fiscal year 1990 on basic research and over $10 billion on applied research. Research thus represents 1.8 percent of the total Federal budget (at $1.2 trillion). This 1.8 percent, or roughly $21 billion, is an abstraction referred to as the "Federal research budget. "[10]

Funding for research in the United States is led by the Federal Government (47 percent of the national total). Industry is a close second at 42 percent; universities and colleges (the category that includes State and local government funds) follow at 7 percent; nonprofit institutions and others fund the remaining 4 percent. Industrial support of basic and applied research has grown dramatically over the

5 Harvey Brooks, "Can Science Survive in the Modem Age?" *Science,* vol. 174, Oct. 1, 1971, p, 29. Brooks goes onto caution that a strong basic science is not a *sufficient* condition. For a recent postscript, see Harvey Brooks, "Can Science Survive in the Modem Age? A Revisit After Twenty Years," *National Forum, vol.* 71, No. 4, fall 1990, pp. 31-33.

6 The question asked was: "AS far as the people running these institutions are concerned, would you say you have a great deal of confidence, only some confidence, or hardly any confidence at all in them?' Since 1973, from 37 to 45 percent of the respondents indicated ". . . a great deal of confidence.'' See National Science Board, *Science and Engineering Indicators-1989,* NSB 89-1 (Washington, DC: 1989), p. 172 and app. table 8-11.

7 Respondents in 1985 were asked: "Do you think it is very likely, possible but not too likely, or not at all likely that this result will occur in the next 25 years?" National Science Board, Science *and Engineering Indicators—1987,* NSB 87-1 (Washington DC: 1987), p. 150 and app. table 8-10,

8 The respondents were asked to tell, for each problem, ''. . . if you think that the government is spending too little money on it, about the right amount, or too much. " See National Science Board, op. cit., footnote 6, p. 174 and app. table 8-13. A sample of British respondents were asked the same question in 1988. Improving health care and helping older people topped their list, while 47 percent (v. 34 percent of the U.S. sample) expressed a desire for increased government funding of scientific research.

9 In empirical terms, "research" has changing referents in the report. Sometimes a measure refers to "academic" or "university" research, other times to ''basic' research. The reader is alerted to these different performers or activities as OTA reviews them and the sources of information used to characterize scientific research.

10 The research figures are current dollar estimates. See Albert H. Teich et al., *Congressional Action on Research and Development in the FY 1991 Budget (Washington* DC: American Association for the Advancement of Science, 1990). Other figures are computed from various sources cited in table 1-2.

Box 2-B-Public Interest in Science

At a time when U.S. society has embarked on more technological adventures than ever before, Americans apparently understand less about science and technology than citizens in other western countries. But understanding alone is not the issue; rather, it is the complex relationship among public understanding, public confidence in science and technology, and the public interest.[1] From the turn of the century through World War II, American technology and science came into its own. New inventions for the benefit of consumers were talked about everywhere from the Sears and Montgomery Ward catalogs to popular magazines; stories about the new invention, the telephone, were plentiful; and even if not everyone understood the new technology, they had confidence in it.[2]

Military technology, given its lasting impact on everyone's lives during wartime, seemed easier to fathom "back then." Soldiers understood how a gun worked; stories abound about how American GI's were able to fix things on the spot, using whatever spare parts they could lay their hands on. People thought they understood the technology that surrounded them and that it was essentially beneficial.[3]

With the development of the atomic bomb (necessarily shrouded in secrecy) came the end of innocence. The shattering of Hiroshima and Nagasaki was accompanied, for many, by a shattering of faith in science and technology as forever benign and helpful. In ways that we have only now begun to understand, the image of destruction associated with the atom bomb has affected all technology, certainly all technology associated with nuclear power and nuclear waste, With Three Mile Island, Bhopal, the Challenger accident, and Chernobyl, this image of destruction has become the paradigm, for many, of all science and technology.[4]

The discovery of restriction enzymes that slice strands of DNA into separate pieces, and that DNA pieces from different species will connect with each other, has given rise to the great hope of understanding and curing genetic diseases. Yet it also has raised fears of somehow disturbing the natural universe, changing things that ought not be tinkered with. To know more sometimes is to fear more: "unintended consequences" is today a familiar refrain; even good intentions have side effects.

The very advance of biological and medical knowledge itself leads to frustrations and contradictions, further undermining confidence in science. If we can perform the miracle of organ transplants, why can we not cure multiple sclerosis? If we can cure childhood leukemia, why not lung cancer? *Science* editor Daniel E. Koshland writes:

> But as architects of change, we [scientists] have occasionally oversold the product, implying that it will bring unmixed good, not acknowledging that a scientific advance is a Pandora's box with detriments or abuses as well as benefits. By confessing that we are not omniscient we may lose some awe and admiration, but we will gain in understanding and rapport.[5]

What can the scientific community do? Despite some negative feeling about science, or some aspects of it, there are indications that the public is more interested in it and more willing to make the effort to learn than they are given credit for. Although 20 percent of college graduates earn science and engineering degrees, many more enter college eager to learn science.[6] The television program "NOVA" which covers all aspects of science, is consistently among the more highly watched programs on public television. And 95 daily newspapers across the Nation have weekly

[1] This box is adapted from Alan H, McGowan, president, Scientists' Institute for Public Information, who wrote it expressly for this OTA report under the title "Public Understanding of Science' For an overview of the relationship between public interest, understanding, and confidence, see Kenneth Prewitt, "The Public and Science Policy," Science, *Technology, & Human Values*, vol. 7, spring 1982, pp. 5-14.

[2] One of the best descriptions of this phenomenon is to be found in Daniel J. Boorstin, The *Americans: The Democratic Experience* (New York, NY: Vintage Books, 1974).

[3] There is a difference between understanding the scientific principles behind an invention or technology and having *a* general idea of how the parts fit together or what sequence of events must occur to make the technology work.

[4] See Daryl E. Chubin, "progress, Culture, and the Cleavage of Science From Society," *Science, Technology, and Social Progress,* S.L. Goldman (cd.) (Bethlehem, PA: Lehigh University Press, 1989), pp. 177-195; and "Is Knowledge a Dangerous Thing?' *The Economist*, vol. 318, Feb. 16, 1991, pp. 21-22.

[5] Daniel E. Koshland, "To See Ourselves As Others See *us,*" Science, vol. 247, Jan. 5, 1990, p. 9. For a content analysis of how popular magazines portrayed science in the first half of the 20th century, see Marcel C. LaFollette, *Making Science Our Own: Public Images of Science 1910-1955 (Chicago,* IL: University of Chicago Press, 1990),

[6] u.s. Congress, Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering*, *OTA-TM-sET-* **41** (Washington DC: U.S. Government Printing Office, December 1988), ch. 1.

Continued on next page

Box 2-B—Public Interest in Science-Continued

science sections which, according to their editors, are among the most highly regarded sections in the paper. This represents a growth from 66 such sections in 1986 and 19 in 1984.[7]

The attitude in the scientific community has also changed. Fifteen years ago, most scientists avoided the popular press. Now, many scientists and engineers relish being quoted.[8] Still, working to improve public understanding is not rewarded in many ways within the scientific community; the time is taken from other pursuits, and therefore can be costly to one's career.[9]

What mechanisms would encourage more involvement by scientists and engineers in raising public interest in and understanding of science efforts? Congress might include required spending of a portion of research grants on public understanding efforts, designating a fraction of each agency's budget for an office devoted to help grantees develop public understanding efforts, and giving awards to scientists who have made substantial contributions to public understanding.[10] At a time when more and more of American life is rooted in science and technology, and when the Nation's economic well-being depends as never before on its understanding and utilization, the Federal Government cannot be complacent about the public's interest and confidence in science.[11]

[7] "Newspaper Science Sections Still on the N*, ' *SIPIscope*, vol. 18, spring 1990, p. 1. As one science policy statesman writes: "I have come to believe . . . that the way things will work out for American science is very much in the hands of communicators--+f science writers and reporters. They are a breed of science watchers, and the last thing in science's interests is to patronize or condescend to them. ' William D. Carey, "Scientists and Sandboxes: Regions of the Mind,'' *American Scientist, vol. 76,* March-April 1988, p. 144. Also see Maurice Goldsmith, *The Science Critic* (London, England: Routledge & Kegan Paul, 1986).

[8] In addition, as sociologist Dorothy Nelkin puts it: "Dependent more on political choices than peer *review,* many scientists in the 1980s *became* convinced that scholarly communication was no longer sufficient to assure support for their costly enterprise, that national visibility through the mass media was strategically essential. They greatly expanded efforts to work the media, trying to shape the images conveyed. ' Dorothy Nelkin, "Selling science," *Physics Today*, November 1990, p. 45. Also see the special issue in which this article appears, ''Communicating Physics to the Public,' *Physics Today, November* 1990, pp. 23-56.

[9] See Neal E. Miller, *The Scientist's Responsibility for Public Information (New* York, NY: Scientists' Institute fOr Public Information, Media Resource Service, 1990); and John P. Donnelly, ''Rese-archers Must Join Forces to Bolster Public Confidence and Funding Support,'' *The Scientist,* vol. *4, No. 20, Oct.* 15, 1990, p. 16.

[10] Precedents for such activities include a l-percent set-aside in the budgets of the National Institutes of Health (NIH) for evaluation of NIH research, and the annual "public Understanding of Science and Technology'' awards given to science journalists by the American Association for the Advancement of Science and Westinghouse.

[11] Greater public understanding of science will not necessarily lead to greater Federal funding of research. As one commentator observed a generation ago: ''Although there is no question that the public has demonstrated its willingness to provide . . . support, I doubt whether the intrinsic cultural value could be used to justify to the public or to politicians more than a small fraction of the present support for basic science in the United States, or indeed in any other major country of the world. ' Harvey Brooks, "Are Scientists Obsolete?'' *Science,* vol. 186, Nov. 8, 1974, p. 508.

last 20 years, especially in the early and mid-1980s.[11] For basic research alone, the Federal Government funds 62 percent of the total, followed by industry (21 percent), universities and colleges (12 percent), and nonprofit institutions and others (5 percent).[12]

While questions of relative funding can be gauged with funding data (e.g., comparisons between Federal and industrial support), it is not easy to compare expenditures in one year to those in another. Economic change affects the "value" of a dollar over time. Because some goods (foodstuffs, automo-

[11] The national R&D effort is funded primarily by the Federal Government, industry, and academic institutions. In 1990, industry and the Federal Government together accounted for nearly 96 percent of total support, with universities and colleges contributing 3 percent, and other nonprofit institutions funding 1 percent. Industry is the largest single source of R&D funds, providing $74 billion compared to the Federal Government's $69 billion, and the past decade represents a period of great growth in industrial R&D spending. National Science Foundation, *National Patterns of R&D Resources: 1990*, NSF 90-316 (Washington DC: May 1990), table B-5.

[12] For these aggregate figures, the National Science Foundation estimates of basic/applied/development breakdowns-despite some fuzziness in labeling-are thought to be reliable. See ibid.

Photo reedit: Jay Mangum Photography

This research is part of an acid rain study in the Duke Forest Project, NC. Research can take many forms, from space exploration to the study of microbes, and almost all are represented in the Federal research portfolio.

biles, housing) change slowly over time, economists have developed so-called constant dollars or ''deflators' to use in comparing economic activity in two or more years. Constant dollars work less well for goods that change rapidly (e.g., computers, consumer electronics, and defense technologies), and not at all for products that, by definition, are dissimilar from one year to the next.[13] The use of any two deflators can also lead to very large differences, especially as the timeframe lengthens. Taking into account these difficulties in the use of deflators for comparing research funding over time, OTA has chosen to use the ''Gross National Product Implicit Price Deflator. " This deflator reflects changes in total public and Federal expenditures. Thus, OTA's figures can be easily compared, as Congress routinely does, with trends in other public expenses.[14] (Box 2-C discusses different deflators and their use in interpreting trends in research funding.)

Documenting Perspectives on the Future of Research

The American public holds scientific research in high esteem, but does not see it as the Nation's top priority. This contrasts with survey findings of the late 1980s and 1990 reflecting the perceptions of scientists and engineers. Biomedical researchers in academia and industry, recombinant DNA researchers, young faculty researchers in physics, and a cross-section of Sigma Xi (The Scientific Research Society) members all report difficulty in establishing or sustaining research programs and fear reductions in Federal funding for individual-investigator research (which they see as a ***top*** funding priority) .15 Perhaps the most forceful recent advocate of increased research funding is Nobel laureate physicist

[13] In this construction, research is a ' 'product' i.e., has measurable outputs. But the value of the output is not determined by market prices. would be more accurate perhaps to treat research as a ''process," i.e., an activity or service to the economy.

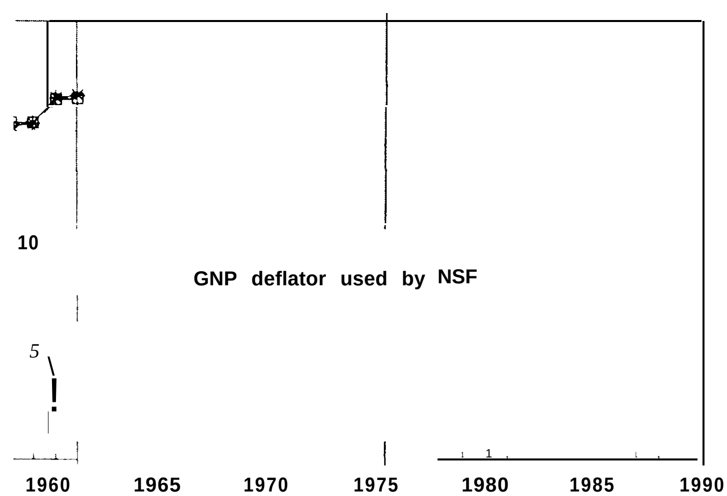
[14] The executive branch perspective is contained in the *Economic Report of the President* (Washington DC: U.S. Governm ent Printing Office, 1990).

[15] See, respectively, Gallup poll results reported by the Pharmaceutical Manufacturers Association Foundation, Inc., Losing *Ground in Biomedical Research: The Shortage of American Scientists* (Washington, DC: February 1991); Isaac Rabino, "The Impact of Activist Pressures on Recombinant DNA Research,'' *Science, Technology, & Human Values*, vol. 16, No. 1, winter 1991, pp. 70-87; American Physical Society survey results reported in Roman Czujko et al., "Their Most Productive Years: Young Physics Faculty in 1990," *Physics Today*, February 1991, pp. 37-42; and Political Economy Research Institute, "Researcher Perspectives on the Federal Research System," OTA contractor report, July 1990 (available through the National Technical Information Service, see app. F).

Box 2-C--Calculating Constant Dollar Trends for Research

While seeming a trivial problem at first glance, calculating funding trends for research in constant dollars (i.e., units that have the same spending power in each year) can be full of pitfalls. Different methods can lead to quite different trends and, therefore, policy conclusions. For example, the constant dollar values calculated using a method developed at the Department of Commerce (and used by the National Science Foundation) imply that research expenditures in the United States have grown by roughly 40 percent in the period 1%9 to 1990, Similar calculations based on a method developed by the Office of Management and Budget (and used by the American Association for the Advancement of Science) imply that research expenditures have grown by less than 15 percent (see figure 2C-1).[1]

Figure 2C-1—Federal Research Spending in Constant Dollars Using Two Different Deflators: Fiscal Years 1960-90 (In billions of 1982 dollars)



KEY: R&D. Research and Development; OMB - Office of Management and Budget; AAAS. American Association for the Advancement of Science; GNP . Gross National Product; NSF. National Science Foundation.

SOURCES: Current dollar data came from National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-1990* (Washington, DC: 1990), table A; and National Science Foundation, Selected *Data on Federal Funds for Reseach and Development: Fiscal Year 1989, 1990 and 1991* (Washington, DC: December 1990), table 1. Deflator data came from the Office of Management and Budget, Budget Analysis and Systems Division, unpublished data; and National Science Board, Science and *Engineering Indicators--1989, NSB* 89-1 (Washington, DC: 1989), app. table 4-1.

So how does one **calculate a constant dollar** trend? The object is to translate dollars from one year to the next, i.e., to find the price of a market basket of commodities. The deflator is the ratio of the purchasing power of a dollar for a particular year to that of a reference year. A change in the index means that purchasing power has changed with respect to the same market basket. This change can also be expressed as ''constant dollars, such as ''1982' or 1988' dollars. These ratios can then adjust any dollar amount for a given year to get a value in constant dollars.

A set of ratios or indices for a series of years is called a' 'deflator. " To calculate a deflator, a comparison must be made between how much a specific thing costs in the year in question and in the constant dollar year. The differences between methods used to calculate constant dollar trends depend on what goods or services are tracked to make up the deflator. For instance, increasing salaries are very different from increasing (or decreasing) prices of computers.

Congress is most interested in comparing research expenditures to other elements of the Federal budget. Thus, a deflator that represents expenditures on products and services that are often bought throughout the United

[1]Informal meeting on deflators, hosted by the American Association for the Advancement of Science, Dec. 5, 1990. OTA notes that the National Institutes of Health uses its own deflator, called the Biomedical Research and Development Price Index, which is discussed in ch. 6.

States-a constant dollar in the most general sense-is often the most useful for congressional policy analysis. Using the Gross National Product (GNP) Implicit Price Deflator developed by the Department of Commerce is usually acceptable, since it employs a large market basket of goods to calculate its constant dollar ratios.[2] Constant dollar trends for research calculated with this deflator compare research expenditures to other expenditures throughout the economy.

In other contexts, a deflator that specifies indices relating only to research (salaries, facilities, and instrumentation) could be preferable, In such a deflator, if 45 percent of total expenditures for research goes to salaries,[3] 45 percent of the deflator would reflect the changes in these salaries. When other components of the deflator are similarly adjusted-equipment, facilities, and indirect and other costs-a new index is derived. Use of such an index to adjust total research expenditures would approximate how much scientists were spending in one year as if the prices and contents of the market basket of goods and services were unchanged (i.e., the effect of increasing salaries and cost of equipment and other items would have been removed).[4] Deflators are difficult to calculate for science and engineering research, because the items and mix of the market basket cart change rapidly and they may be quite different in separate fields of inquiry. In addition, even a ''correct' deflator of this type can be misleading because it only concerns inputs and not the changing character of research outputs, i.e., one is not buying the same science and engineering "product."

Given the problems with research-specific deflators and the advantage of a general GNP deflator to compare expenditures across the economy, all constant dollar figures and tables in this report were calculated with the GNP Implicit Price Deflator for 1982 dollars (unless noted otherwise). However, OTA does not make any specific policy assumptions based exclusively on constant dollar trends.

[2] *Economic Report of the President,* Transmitted to Congress February 1990 (Washington, DC: U.S. Government Printing Office, 1990), pp. 298-299, table C-3.

[3] See ch. 6 of this report.

[4] No deflator has been created using this method. Bmce Baker, Office of Management and Budget, personal communication, Nov. 26, 1990. But see a pair of working papers by John E. Jankowski, Jr., National Science Foundation, ' 'Do We Need a Price Index for Industrial R&D?' n.d.; and ''Construction of a Price Index for Industrial R&D Inputs, " Aug. I, 1990. Among the approximatiions used is the Office of Management and Budget noncapital Federal expenditures deflator developed to normalizeall expenditures Of the Federal Government that do not involve the specific procurement of large, capital ite ms—obviously a much larger set of expenditures than those involved in research. As stated by Bruce Baker, Office of Management and Budget: "This is nor an R&D deflator, it is a deflator used to deflate R&D. " American Association for the Advan cement of Science, op. cit., footnote 1. The problem with the use of this deflators that even though it excludes many expenditures unrelated to research, the expenditures that are reflected in the deflator are not guaranteed in any way to mimic research expenses over time. Consequently such a deflator may be just as ''wrong' as any other deflator to calculate research productivity.

Leon Lederman, who also relies on a survey of active researchers in major universities (see 'box 2-D).

Such surveys can take the pulse of a population, tapping respondents' perceptions, experiences, and feelings. Other data, however, must be assembled and analyzed to provide a more systematic, well-rounded characterization of the state of affairs-and general health---of the Federal research system. That is OTA's objective in this report.

Although scientists may now feel engulfed by the stress of research competition, the Federal research system and the place of U.S. science in the world has remained strong. Other countries support research infrastructures at the forefront of many fields—which is expected in an internationally competitive economy—but U.S. science still ranks at or near the top in most fields. This is a testament to the strength and scale of federally funded research.[16]

This system will face many challenges in the 1990s, including living with tight fiscal conditions. In the 1980s, four categories of Federal spending consistently increased in constant dollars: defense, entitlements (Social Security, Federal retirement,

[16] There is evidence that the United States is a latecomer to the stresses beleaguering other nations. See Susan E. Cozzens et al. (eds.), *The Research System in Transition,* proceedings of a NATO Advanced Study Institute, 11 Ciocco, Italy, Oct. 1-13, 1989 (Dordrecht, Holland: Kluwer, 1990). The question of whether the United States is ''losing ground" to other nations very much depends on which fields or research areas are of concern, and which indicators of research productivity one chooses to embrace. For evidence to the contrary, see Gina Kolata, "Who's No. 1 in Science? Footnotes Say U.S.' New *York Times,* Feb. 12, 1991, pp. Cl, C9; and "No Slippage Yet Seen in Strength of U.S. Science, " *Science Watch,* vol. 2, No. 1, January/February 1991, pp. 1-2.

Box 2-D—An Interpretation of Researchers' Distress by Leon M. Lederman

On January 7, 1991, Leon M. Lederman, Nobel laureate physicist and President-Elect of the American Association for the Advancement of Science (AA/M), sounded "a cry of alarm" for academic science. He released a report to the AAAS membership expressing concern ''. . . far the future of science m the United States and for the profound cultural and economic benefits that science brings. "[1] The following are excerpts from the report, which was based on an informal survey of natural sciences faculty in 50 U.S. universities, including the top 30 institutions in Federal R&D funds received. The survey yielded letters from 250 scientists. The text below is an excerpt from Lederman's report and is followed by a postscript written by him expressly for this OTA report.[2]

The responses paint a picture of an academic research community beset by flagging morale, diminishing expectations, and constricting horlzons. . .

> (There were) three incidents where we had to stand by while competitors from abroad moved forward on research based on our ideas. ., . The history of the past decade is one of continued harasssment over roomy, lost opportunities due to inadequate support, and a stifling of Imagination due to money worries If U.S. scientists must continue to stand by and watch as our best ideas are carried forward by groups from abroad, our nation cannot hope to escape a rapid decline.
>
> -Professor of Physics,
> Massachusetts Institute of Technology

. Academic science has not arrved at its present state through a conscious decision by the Administration or Congress, No political leader has advocated starving science-- indeed, most feel that they support it strongly, Presidents Reagan and Bush have both promised to double the size of the National Science Foundation's budget within five years, and Congress, almost every year, appropriates more for the National Institutes of Health than the Administration requests, . . .

However, recent growth has been insufficient to compensate for the effects of the long drought that preceded it, Thus, In the view of those in the laboratorles, there has been a gradual year-by-year erosion in the availability of funding and h the health of academic science over nearly two decades, . . .

> I suspect that if I were twenty years younger I would not choose an academic research career. Even now I find myself considering other options. I'm Wed of writing 'excellent' proposals that aren't funded.
>
> -Professor of Chemistry,
> Duke University

The (funding) problem is compounded , . . by a number of other factors that, taken together, further restrict the results that can be obtained from each research dollar, One factor Is complexity--or what same observers have called "sophisticated inflation, " As our understanding of nature Increases, the questions we need to answer became more complex. There is a corresponding Increase in the sophistication (and cost) of the equipment needed to do research, both for small, "table tap" experiments and large facilities such as telescopes and accelerators .... The cost of regulation is a second factor. In many fields, particularly in the life sciences, increased regulation absorbs significant funds and research time. . . . A third factor is institutional overhead. According to the National Science Foundation, indirect costs at universities (including admlnistration, maintenance of buildings, utilities, etc.) have risen from 16 percent of the national academic R&D budget In 1966 to about 28 percent in 1986... .. . (and this) means that less money is available to the laboratory scientist for the direct costs of research. . . .

The problem is more serious than average grant size or proposal success rates (at the National Science Foundation and the National Institute of Health), however. The letters reveal potentially important changes in the way scientists as individuals pursue their craft. As a consequence of the increasingly difficult search for funding, academic scientists are less willing to take chances on high risk areas with potentially big payoffs, Instead, they prefer to play it safe, sticking to research in which an end product is assured, or worse, working in fields that they believe are favored by funding agency officials, These scientists are also increasingly viewing their fellows as cornpetitors, rather than colleagues, leading to an increasingly corrosive atmosphere. The manifestations of this attitude range from a reluctance to share new results with other scientists to public bickering about relatlve priorities in funding different fields,

> We are tending to do "safer" projects, avoiding the high risk, but high payoff projects. In the present climate we cannot afford to have experiments not work .. . . Undergr aduates, graduate students and postdocs continually ask about the benefits of pursuing an academic career when funding is so tight.
>
> —Assistant Professor of Biology,
> Carnegie-Mellon University

[1] Science: The End of the Frontier? a report from Leon M. Lederman, president-elect, to the Board of Directors of the American Association for the Advancement of Science (Washington, DC; American Association for the Advancement of Science, January 1991).

[2] OTA does not necessarily agree with the conclusions either m the report or the postscript.

...(in addition) respondents reported that they are cuttinng back on the number of students they are trainlng, and that students now In the laboratories are opting out of research careers.

> While the current loss of productive groups is serlous, even more disturbing is the negative influence the present difficulties are having on the next generation. On a recent visit to MIT I had an informal lunch with about twenty graduate students in organic chemistry and asked how many of them were going into academic science. One person raised his hand and he was returning to a small liberal arts college where he hod been a student. This group agreed that thelr lack of interest in unlversity level positions is thelr perception that the challenge of gaining funding is now dominant over the challenge of the science.
>
> -Professor of Chemistry,
> University of Illinois

What would It take to relieve the acute problems In academic research and restore U.S. science to its pre-1968 excellence? Let us consider this question Independently of "practical" constraints dictated by current events. My analysis.... indicates that we should be spending at least twice as much as we were In 1968 (In constant dollars) if we are to approach the conditions of [this era). Indications from NSF, NIH and DOE tend to confirm the pressure for a doubling of the current level of funding for academic science, which amounts to about $10 billion a year This huge sum could, I believe, be effectively deployed In two or three fiscal years.

Beyond this, in future years, I would argue that the growth of four percent per year In the number of academic scientists and the complexity factor growth estimate of five percent per year imply that a sustained flourishing of academic research requires annual real growth of eight to ten percent.... Such an Increment may sound substantial in our current climate, but as the economy responds, academic research would remain only a tiny fraction of total federal spending for many decades. Furthermore, even with such Increases, it would be a decade or two before our level of nondefense research expenditure proportional to GNP would equal the 1989 levels of Japan or West Germany.

February 1991 Postscript

In his budget for FY 1992, the President requested significant increases for science, averaging 5-10 percent above inflation. In view of the fiscal constraints, scientists must stand In awe at the respect their work has earned. This is the eighth year of real increases initiated by the Administration and passed by Congress. Nevertheless, the AAAS Inquiry has dramatically confirmed indications of serious troubles at the laboratory bench.

There are several reasons for believing that, In spite of these Increases, the Nation is seriously underinvesting in research. One is the comparison with what our economic competitors are doing. Another is the comparison of our relative research capability today with what It was in the late 1960s.

International prizes (identifying when the work was done) as well as patents and a hard-to-quantify loss of scientific and technological self-confidence paint in the same direction, The unprecedented stress within the scientific community described above is another indicator.

The crisis documented in the AAAS survey must be viewed as part of a larger pattern of national decisions. My analysis indicates that a continuation of the kind of investment we were making in the 1960s would have brought us today to somewhere near $30-40 billion for academic research. This is what motivated the "unrealistic" proposal for a doubling of the budget with subsequent 8-10 percent annual Increases for at least a decade,

We are keenly aware that we have concentrated on only one important element of a problem that must include many other components, such os non-military R&D in industry and the national laboratories, and the overall scientific literacy of the work force, Research and education are so intimately entwined that they must be treated together. Only very briefly mentloned in the report are the human resources devoted to what economist Robert Reich calls "strategic brokers," those who translate R&D results into economic products. The record of U.S. investment in research and education, even given the increases, is one of decline relative to the GNP and relative to other industrialized societies. Whereas it is surely true that sums allocated by the Federal Government could always be spent more efficlently (especially in education), the problem is clearly underinvestment. Yet the primary asset of a modern industrial nation in the 21st century is its brainpower: a skilled, educated workforce.

The vision to recognize this os a salient feature of our times resides in many of our leaders. No doubt some such perception explains the favoring of science in tough times. However, the resources that are really demanded are far greater, as has been "unrealistically' proposed In the AAAS report. Nevertheless, if these human capital investments are judged in the context of a $5 trillion GNP or a $1.4 trillion Federal budget. It becomes clear that the issue isn't cost---it is a matter of choice, The choice is to treat the human resources of the Nation------an educated, capable work force--as the key to a successful society. If we choose wisely, and I let my imagination soar, the expenditure for academlc scientific research will one day reach $50-100 billion (In 1991 dollars). With commensurate Investment in education and infrastructure, we can restore not the world leadershlp we once enjoyed, but the position of the Nation as a dynamic and resourceful society, a leading participant in the new global economy of the 21st century. If we fail to see this long term issue, if we are dominated by our "third quarter" crises, if we hesitate because we have lost faith In the power of the human mind, our long term prospects will be dismal Indeed.

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Medicare, and Medicaid), net interest on the Federal debt, and Federal spending on research.[17] While the deficit continues at record levels, the Omnibus Budget Reconciliation Act of 1990 will temper Federal spending, including possible modifications and further priority setting in expenditures for research. 18

In addition, the scientific community has grown in size since the 1960s, reflecting a rising research economy that supported the pursuit of many spectacular opportunities. However, as more knowledge is gained, expenditures for cutting-edge research have also increased. These factors have combined to magnify the burdens on research performers and institutions, and on the Federal sponsors that fund them.[19] Many in the research system also wonder, as the uncertainty increases over enrollments by U.S. students in science, whether the next generation of scientists and engineers will sustain the research enterprise.[20] The pressures mount on public policy to decide which opportunities are most urgent, which agency programs to favor, and the rationale for supporting a diversity of fields, sectors, and research personnel. In the words of Yale Medical School Dean Leon Rosenberg:

> The scientific community is responsible in a major way for the paradoxes and dilemmas in which we find ourselves. . . . There are more opportunities than ever to ferret out the secrets of human biology and apply those secrets to the reduction of human suffering. The dilemma is that we must obtain more funding for the support of this effort in order to capitalize on those opportunities and improve the morale of the scientific community, while at the same time acknowledging that we have been generously supported for the past 40 years.[21]

This report explores the 'paradoxes and dilemmas' of supporting U.S. science in the 1990s, while this chapter introduces the history of the Federal research system and current challenges that demand Federal policy attention.

Historical and Current Federal Roles in the Research System

The Federal research system has many participants. They include Congress, the Federal research agencies, the Office of Management and Budget (OMB), the Office of Science and Technology Policy (OSTP), academic research institutions, Federal and industrial laboratories, the National Academy of Sciences complex, professional societies, think tanks, and others.[22] Together these components sponsor, per-form, and guide the activity called ''research.

Recognition of the role of the Federal Government in the support of research grew during the early parts of the 20th century, especially before and immediately after World War II. During the 1930s and 1940s, the Departments of Defense (DOD) and Agriculture (USDA), the Public Health Service (largely through the National Institutes of Health, NIH), and the Atomic Energy Commission (then, the Energy Research and Development Administration, and now the Department of Energy, DOE) collectively funded a diverse Federal research portfolio.[23] In the 1950s, the National Aeronautics and Space Administration (NASA) began to sponsor space exploration projects, and in the 1960s, it launched a celebrated and successful effort to safely land humans on the Moon and to gather data on the solar

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17 ''Outlays by Category, " *Government Executive, vol. 22,* September 1990, p. 44.

18 See Jeffrey Mervis, ''Science Budget: A Zero-Sum Game,' *The Scientist,* vol. 4, No. 24, Dec. 10, 1990, pp. 1,6; and David C. Morrison, ''Pinching the Research Budget,'' *National Journal, vol. 22, No. 49,* Dec. 8, 1990, p. 2996.

19 See William D. Carey, "R&D in the Federal Budget: 1976- 1990," and Rodney W. Nichols, "Mae West at Olympus: Five Puzzles for R&D," both in *Science and Technology and the Changing World Order,* colloquium proceedings, Apr. 12-13, 1990, S.D. Sauer (cd.) (Washington, DC: American Association for the Advancement of Science, 1990), pp. 43-51, 53-69.

20 The gap between current rhetoric and current problems in science education as they relate to the Nation's research capability is examined in Iris Rotberg, ''I Never Promised You First Place,' *Phi Delta Kappan,* vol. 72, December 1990, pp. 296-303.

21 Quoted in Dick Thompson, "The Growing Crisis in Medical Science," *Time,* Dec. 17, 1990, p. 21.

22 Because universities perform the preponderance of basic and applied research and train most of the research work force, and because much Of the data on research performance has been collected on academia, this report often focuses on academic research performers. However, when relevant, and especially where data are available, other performers are discussed.

23 See Margaret W. Rossiter, ''Science and Public Policy Since World War II, '*Historical Writing on American Science: Perspectives and Prospects,* S.G. Kohlstedt and M.W. Rossiter (eds.) (Baltimore, MD: Johns Hopkins University Press, 1986), pp. 273-294; and Julius H. Comroe, Jr., *RetroSpectroScope: Insights Into Medical Discovery* (Menlo Park, CA: Von Gehr Press, 1977).

system. Federal research was supported and selected in partnership with the scientific community and with little constraint to adhere to formal agency missions.[24]

For many years, the core of the national effort in science was increasingly understood to reside in and be expressed through the National Science Foundation (NSF).[25] A 1965 National Academy of Sciences report, *Basic Research and National Goals*, went so far as to state that:

> . . . the National Science Foundation is viewed . . . as being responsible for. . . "intrinsic basic science,' the motives for which are relatively remote from politically defined missions. Since this is a social overhead whose connection with specific applied objectives of the society is distant and undefined, it would seem. . . that allocation of resources to this activity would be even more difficult than the allocation to mission-related research.[26]

Since NSF primarily funded research in universities, science policy was generally equated with the provision of resources for research, principally through the university-based research system.

Although DOD, NASA, DOE, and USDA had significant basic and applied research budgets in the 1960s and 1970s, and NIH finding soared with the War on Cancer in the early 1970s, it was not until the 1980s that infusions in defense research and development (R&D) and the debates over the importance of federally sponsored applied research once again highlighted the pluralistic Federal role.[27] "The fragmented, mission-oriented structure that emerged after World War II went a long way toward realizing Vannevar Bush's vision of a Federal system for the support of science and engineering. In large measure, it was responsible for the emergence of the great American research universities and the 'golden age' of science. '[28] Today, research is understood to be an activity pursued in many agencies of the Federal Government and sectors of the U.S. economy.[29]

The wisdom of the compact between science and the Federal Government has been demonstrated repeatedly in the last half of the 20th century. As more and more has been explicitly demanded of scientific and technological institutions in U.S.

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[24] See U.S. Congress, House Committee on Science, Space, and Technology, Task Force on Science Policy, *A History of Science Policy in' the United States, 1940-1985*, 99th Cong. (Washington DC: U.S. Government Printing Office, 1986), especially pp. 15-40; also see Alan T. Waterman, "Basic Research in the United States," *Symposium on Basic Research,* Dael Wolfle (cd.) (Washington DC: American Association for the Advancement of Science, 1959), pp. 17-40. The celebrated Mansfield amendment, passed as part of the fiscal year 1970 Military Authorization Act (Public Law 91-121), prohibited military funding of research that lacked a direct or apparent relationship to specific military function. Through subsequent modification, the Mansfield amendment moved the Department of Defense toward the support of more short-term applied research in universities. For a discussion see Genevieve J. Knezo, "Defense Basic Research Priorities: Funding and Policy Issues,' CRS *Report for Congress* (Washington DC: Congressional Research Service, Oct. 24, 1990), pp. 5-9.

[25] While the Bush Report and the Steelman Report (introduced inch. 1) were both effusive in their praise of the social benefits emanating from scientific advance and the underlying rationale for the Federal support of science, each took a different approach to the administration of a national science foundation. OTA points out that ". . the Steelman report regarded science as a special interest, Although large-scale government support for science was a new phenomenon, science was not considered to be sufficiently different from other policy areas to warrant any special political relationships. " Bush supporters were". . . convinced that science was distinct from other types of government programs, that it must be free from political control, and that, to be successful, scientists should be able to direct their own affairs. . . . Scientists, . . . through advisory groups and a system of review by scientific peers, would decide how research should be conducted and would influence the research agenda." See U.S. Congress, Office of Technology Assessment *The Regulatory Environment for Science,* OTA-TM-SET-34 (Springfield, VA: National Technical Information Service, February 1986), pp. 15-16.

[26] George B. Kistiakowsky, "Summary,' in National Academy of Sciences, Committee on Science and Public Policy, *Basic Research and National Goals,* A Report to the Committee on Science and Astronautics, U.S. House of Representatives (Washington DC: March 1965), p. 11. This collection of essays evolved, in the words of Committee Chairman George P. Miller, into ". . . the production of a comprehensive study designed to throw into bold relief some of the more serious phases of policy which Government must consider in its decisions to support or otherwise foster research in America." (p. v).

[27] From the researcher's perspective, multiple sources of Federal support provide funding flexibility, i.e., choice among agencies. From a Federal perspective, flexibility allows choice among alternative research initiatives and performers. New programs can be started or old ones refocused.

'Joseph G. Morone, ''Federal R&D Structure: The Need for Change,' *The Bridge,* vol. 19, fall 1989, pp. 3-13. For a discussion of the "university research economy, " see Roger L. Geiger, "The American University and Research,'' in Government-University-Industry Research Roundtable, *The Academic Research Enterprise Within the Industrialized Nations: Comparative Perspectives,* report of a symposium (Washington, DC: National Academy Press, March 1990), pp. 15-35.

[29] The importance of nonprofit foundations and the private sector in supporting, defining, and utilizing basic research is also indisputable (though the extent of their participation differs greatly by field, industry, and measures of contribution). See National Science Foundation, op. cit., footnote 11.

society, the social contract has changed.[30] A new relationship may be evolving, but the trusteeship remains intact.[31] Today, with the expectation of sustained Federal support of science, concern has shifted to 'how much growth' and 'how to manage expansion." With acute and widespread awareness of the dependency of research institutions on Federal support, money has become the lightning rod of debates over science and other institutional domains. While this is apparent to most decisionmakers, equally important but less visible is the issue of the organization for making policy choices, i.e., how to distribute whatever monies are allocated for research.

Differing conceptions of urgency, time-scale, and level of investment feed tensions within the scientific community as Federal priorities change. In a dynamic, pluralistic system, discontinuities in funding can be expected. The Federal Government is accused of supporting faddish research on the one hand, and of sluggishness in responding to new research opportunities on the other. What is often seen as a choice between big science and little science, or between high-energy physics and molecular genetics, is often more apparent than real. Overall funding decisions are often shaped more by funding allocations between research and other national objectives.[32] As symbolized in the debates over the Superconducting Super Collider and the Human Genome Project, there is a sense of congressional urgency, frustration, and ambivalence over research goals.

While representative democracy ultimately invests the power of decisionmaking in elected officials of the Federal Government (who judge political and national needs), these decisions are tempered by expert advice. Such judgments have consequences for decisionmaking and accountability, especially at the research agencies.[33] More than the other branches of government, Congress-the representative of the public interest-is at the nexus of the trusteeship for research. Congress plays an increasingly active role, both in determiningg the Federal research budget and in stewarding the Federal research system in directions that serve the public good (see chapter 3).

Prospects for the 1990s

Science and engineering are increasingly vital parts of the Nation's culture; research contributes in many ways to the technological and economic base. Since the post-Sputnik era, both the capacity to perform research and the demand for funds to sustain scientific progress have grown. As the research enterprise moves into the 1990s, the Federal research system will experience changing funding patterns and various pressures from both outside and within the scientific community. How, in the face of changing funds and goals, can Congress ensure that the research system satisfies national needs, while retaining the diversity, flexibility, and creativity that have characterized U.S. contributions to scientific knowledge and its payoffs? Four challenges are clear.

First, new methods for setting priorities in research funding will be required. Looking across fields and at objectives that build on, but are not limited to, scientific merit is the responsibility of OSTP, OMB, the research agencies, and the scientific community, as well as Congress. Each may weigh funding criteria differently, but each has a role in preparing the enterprise for tomorrow's research opportunities as well as today 's.

Concern over the amount and distribution of Federal research funding is voiced increasingly throughout Congress. As one former member put it:

> At present we have no well-defined process . . . for systematically evaluating the balance of the overall Federal investment in research and develop-

[30]For commentary on how 40 years of Federal funding policy strayed from the letter, and perhaps even the spirit, ofVannevar Bush's vision of a centralized system, see Deborah Shapley and Rustum Roy, *Lost at the Frontier* (Philadelphia, PA: 1S1 Press, 1985). The House Committee's Science Policy Task Force concurred with this appraisal in 1986, observing that: "The National Science Foundation, originally conceived as a central coordinating body, was left with a restricted jurisdiction over unclassified, basic research. " House Committee on Science and Technology, op. cit., footnote 24. As Morone, op. cit., footnote 28, p. 4, puts it: "In effect, Bush called for a Department of Science, which would fund research as well as education, natural sciences as well as life sciences, and mission-oriented research as well as general, or 'pure,' science. "

[31]Kenneth Prewitt, "The Public and Science Policy," *Science, Technology, & Human Values,* vol. 7, No. 39, spring 1982, pp. 5-14.

[32]For a discussion, see Genevieve J. Knezo and Richard E. Rowberg, "Big and Little Science," *CRS Review,* February 1988, pp. 6-8; and "Money for the Boffins," *The Economist,* vol. 318, Feb. 16, 1991, pp. 15-16.

[33]Three OTA contractor reports, featured later in this report, provide data on the rhetoric of accountability used byvarious participants in the Federal research system. But see Office of Technology Assessment, op. cit., footnote 25. On the role of the media in promoting accountability, see Marcel C. LaFollette, "Scientists and the Media: In Search of a Healthier Symbiosis, " *The Scientist, vol. 4, No. 14,* July 9, 1990, pp. 13-15.

ment and in the variety of fields that we try to serve. The R&D budgets of the different Federal agencies are evaluated separately and largely independently, both within the executive branch and certainly here in the House and Senate. . . . Of particular interest are the criteria for evaluating competing research development projects in different fields and the organizational arrangements for helping us to do a better job of allocating scarce resources.[34]

Since the support of science and engineering research is vital for the future of the United States, the Federal Government attempts to maintain a strong ''science base,'' i.e., research across a wide range of science and engineering fields.[35] To the extent that specific areas, problems, and projects may be singled out for enhanced finding, debate within the scientific community centers on the adverse impacts of funding large new initiatives, or ''megaprojects, on the science base. The criteria and information to inform priority setting are thus paramount issues, as decisions must be made between competing goals.[36]

A second challenge is that, because demands for research funds are likely to continue to outpace funding in most parts of the research budget, strategies for coping--devised by sponsors and performers alike-will be needed. Congress is especially concerned about the question of costs, because the Federal Government supports research expenditures (e.g., salaries, indirect costs, equipment, and facilities) that have increased over the general rate of inflation. In addition, more researchers are performing federally funded research and, in the aggregate, are spending more across-the-board on their research projects.[37]

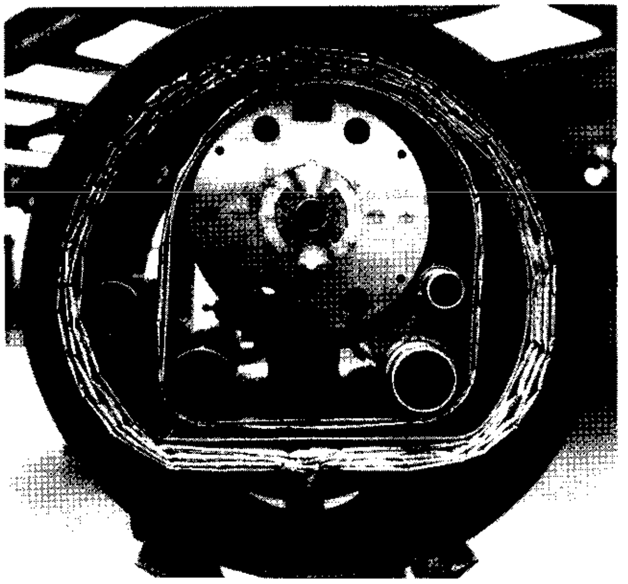

Photo credit: U.S. Department of Energy

This is a cross section of cable destined for the Superconducting Super Collider. Capital expenditures, especially for equipment, are an integral part of most megaprojects.

Recently, the Federal Government has experimented with ways to cope with the rising demands of research, i.e., the expectations that spending will increase in the performance of research. First, Congress imposed salary caps on NIH- and NSF-funded research grants. In fiscal year 1991, legislation relaxed these constrictions. Second, Congress and USDA recently placed a ceiling on the proportion of indirect costs allowable on research grants. This experiment has yet to be fully implemented, but it is expected that universities will attempt to recover

[34]Doug Walgren, Chairman of the House Subcommittee on Science, Research, and Technology, in U.S. Congress, House Committee on Science, Space, and Technology, *The Hearings on Adequacy, Direction, and Priorities for the American Science and Technology Effort*, 101st Cong., Feb. 28-Mar. 1, 1989 (Washington DC: U.S. Government Printing Office,1989), pp. 1-2.

[35]For example, see David Baltimore, ''The Worsening Climate for Biological Research,'*Technology Review, vol. 92, No. 4,* May-June 1989, p. 22.

[36]At the agency level, tradeoffs are made routinely within research programs, and "peerreview' informs the project choice of many Programs, making them accountable to specialized research communities. When criteria in addition to scientific merit are included in peer reviews, however, selection mechanisms can come under duress, See Margaret Jane Wyszomriski, ''The Art and Politics of Peer Review, ' *Vantage Point, spring* 1990, pp. 12-13. For recent appraisals of selection mechanisms and agency accountability for them, see U.S. Congress, House Committee on Science and Technology, Task Force on Science Policy, *Research Project Selection, vol. 17,* hearings, 99th Cong., Apr. 8-10, 1986 (Washington, DC: U.S. Government Printing Office, 1986); and National Science Foundation Office of the Inspector General, *Semiannual Report to Congress, No. 2,* Oct. 1, 1989-Mar. 31, 1990 (Washington DC: March 1990).

[37]Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends, and Issues* (Washington DC: National Academy Press, October 1989), p. 2-32. More qualitative information is needed to understand the contexts of research performance and to interpret the quantitative estimates of time and expenditures reported in various National Science Foundation surveys. For example, see National Science Foundation, *Scientific and Engineering Research Facilities at Universities and Colleges: 1990* (Washington, DC: September 1990).

their costs from the Federal Government by charging more items to direct costs that were formerly part of indirect costs.[38]

Third, addressing the changing demands on the educational pipeline (K-12 through graduate study) for science and engineering will be vital for maintaining strength in the performance of research. Through the direct support of graduate students and the indirect support of research institutions, the Federal Government is pivotal in the creation of a robust research work force. OTA has documented the initiatives needed to maintain the readiness of the educational pipeline. Recruitment and retention programs can respond to changing demands for researchers and enhance preparation for diverse career opportunities for graduates with science and engineering Ph. D.s.[39]

Human resources are the principal component of the research system. Increasing participation in research by those groups chronically underrepresented in science and engineering (women, ethnic/racial minorities, and the physically disabled) and those acutely affected by resource constraints (e.g., young investigators, see box 2-E) is a challenge to the goal of enlarging capacity in the Federal research system. The Nation (not just science and engineering) gains from the flow of new Ph.D.s into this work force. The character of the flow (not just its intensity) will determine the robustness of the research system in the 1990s.

Finally, filling gaps and reducing uncertainties in policy-relevant information is essential for better informed decisionmaking. NSF is defined as *the* Federal agency ". . . to make comprehensive studies and recommendations regarding the Nation's scientific research effort and its resources for scientific activities. '[40] Empirical knowledge about the Federal research system has grown immensely, yet each of the three issue areas outlined above suffers from a lack of some appropriate data on which to base Federal policy.

Photo credit: U.S. Department of Agriculture

A researcher studies the growth of a plant. Increasing the participation of traditionally underrepresented groups in science and engineering will continue to be a focus in federally funded research.

New research indicators are needed as a means of monitoring change in the Federal research system.[41] OTA has also found (see chapter 8) that the evaluation of research projects would add to the investment decisions of policymakers and program

[38]For example, see Colleen Cordes, "Universities Fear That U.S. Will Limit Payments for Overhead Costs Incurred by Researchers,' *The Chronicle of Higher Education*, vol. 37, No. 12, Nov. 21, 1990, pp. A19, A21. For a university perspective, see Association of American Universities, *Indirect Costs Associated With Federal Support of Research on University Campuses: Some Suggestions for Change (Washington* DC: December 1988).

[39]See three repro by U.S. Congress, Office of Technology Assessment: Educating Scientists *and* Engineers: *Grade School to Grad School*, OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988); *Elementary and Secondary Education for Science and Engineering*, OTA-TM-SET-41 (Washington, DC: U.S. Government Printing Office, December 1988); and *Higher Education for Science and Engineering*, OTA-BP-SET-52 (Washington, DC: U.S. Government Printing Office, March 1989).

[40]The National Science Foundation was thus named the agency data liaison and monitor. For the scope of these responsibilities, see especially sections 2-3 and 5-8 of Executive Order 10521, reproduced in J. Merton England, *A Patron for Pure Science: The National Science Foundation's Formative Years, 1945-57 (Washington* DC: National Science Foundation 1982), app. 1, quote from p. 353.

[41]For example, see Carlos Kruytbosch and Lawrence Burton, ' 'The Search fOr Impact Indicators, ' *Knowledge: Creation, Diffusion, Utilization*, vol. 9, December 1987, pp. 168-172.

Box 2-E—The Perils of Being a Young Investigator

"The next generation. " "The seed corn. " "The future of scientific research. " These are some of the words used to describe young investigators. Current commentary on the funding of research grants, especially in biomedicine and by the National Institutes of Health (NIH), centers on the fate of young investigators.[1] This commentary underscores the unity of training and research, yet suggests the strain experienced by a growing segment of the research work force.

Many see the problems of young investigators as a natural adjustment of the research labor market to greater competition in funding or to changes in the structure of research teams. In the words of Rockefeller University President David Baltimore: "How much growth in biomedical research personnel is needed and how much is healthy?"[2] Others see the plight of young investigators as stemming from problems in funding allocation mechanisms. Recognizing that the young investigator with little or no track record is at a disadvantage in head-to-head competition with senior investigators for Federal research funds, both NIH and the National Science Foundation (NSF) have established mechanisms that narrow the pool of eligibles. NIH's First Independent Research Support and Transition (FIRST) awards grant 5 years of support, not to exceed a total of $350,000, to successful first-time applicants to NIH.[3] Begun in 1987, recipients of FIRST awards (R-29s) have indeed fared better than other young investigators in competing for traditional individual-investigator (ROl) funds. In fiscal year 1988, one-half of the R29 awardees were under 36 years of age, compared to 14 percent of RO1 recipients, and 23 percent of the young investigators were female compared to the 14 percent of traditional NIH grant recipients.[4] Perhaps the best news for those who monitor award trends is that once young investigators get an NIH grant, they win renewals as often as senior investigators.[5]

At NSF, the much-heralded (now 7-year-old) Presidential Young Investigator (PYI) program awards 5 years of funding.[6] PYIs are augmented in two directorates by Research Initiation Awards. These provide up to $100,000 for 2 years, including an institutional matching incentive to help defray equipment costs. In 1989,726 applications were received; 17 percent were funded. This constituted mild relief from the slim success rates, roughly one in five, that first-time applicants have experienced since 1984 throughout most NSF programs. (More seasoned investigators have succeeded during that period at a rate of one in three.)[7]

New PhDs ''itch,' in the words of one, to establish their own laboratory, attract graduate students, and produce experimental results. The goal is to replicate the career pattern of one's mentor. But, can every young investigator become a PI? This will bring more proposals, more competition, more demands for research funds. A young investigator with an excellent NIH priority score for her proposal but no money says: "When we slam up against this problem, we have self-confidence to say 'this is unjust,' not 'I am unworthy. ' In a way, it takes an egoist to persevere. "[8]

1Their perils were the major subtext, for example, at the National Academy of Sciences/Institute of Medicine, ''FOIXUII on Supporting Biomedical Research: Near Term Problems and Options for Action,' ' Washington DC, June 27, 1990. In addition, the Nationat Research Council's Commission on Life Sciences is studying the funding of young investigators. A report is due in fall 1991. See "Scientists Explore Ways To Help Young Researc hers," *NewsReport of the National Research Council, vol. 40,* August-September 1990, pp. 6-8.

2Quoted m ''NIH Crowd Seeks New Ways Out of Money Crunch,'' *Science & Government Report, vol. 20, No.* 13, Aug. 1,1990, p. 2.

3See Joe Palca, ''NSF, NIH Apply Band-Aids,'' Science, vol. 249, July *27, 1990,* p. *352.*

4National Institutes of Heal@ Division of Research Grants, ''Briefing on NIH FIRST Activity," spring 1989, pp. 6, 15, 18.

5Palca, op. cit., footnote 3.

6This program awards about 200 grants per year with the expectation that during the *5-year* **period industry funding will be secured to solidify the** investigator's research program and its impact. Even with industrial funding, however, the researcher is likely to apply for regular grant support. A National Science Foundation task force has recently recomm ended cutting the number of Presidential Young Investigator awarded by one-half, increasing the award amount and dropping the matching fund requirement, as well as amending the application process to include a full-blown proposal instead of nominating and endorsing letters from mentors and other senior investigators. See Pamela Zurer, "NSF Young Investigator Program May Be Slashed,'' *Chemical & Engineering News,* vol. 68, No. 50, Dec. 10, 1990, p. 7; and "Presidential Young Investigators" letter, *Chemical & Engineering News, vol. 68, No. 50, Dec. 10,* 1990, p. 5.

7Joe Palca, ''Young Investigators at Risk,'' *Science,* vol. 249, July 27, 1990, p. 353; the National Science Foundation also reports ''new investigator awards, ' i.e., awards to applicants not funded by NSF in the previous 5 fiscal years. Since 1984, 20 to 25 percent of total awards were made to new investigations. See Manpower Comments, vol. 27, No. 5, June 1990, p. 31.

8Palca, op. cit., footnote 7. A junior faculty member at the Salk Institute adds: ' 'I worry because the NIH can't be trusted. The tighter the funding at NIH, the greater the chance your grant will be killed by bad luck--not because it isn't good science. " Arm Gibbons, 'The Salk Institute at a Crossroads," Science, vol. 249, July 27, 1990, p. 361.

Continued on next page

Box 2-E—The Perils of Being a Young Investigator-Continued

Another tack is to be (reluctantly) pragmatic, ". . . buttering up senior researchers and NIH review panel members who could help their chances of getting funded. , . . When good science could get you a grant, you didn't need to do it. Now you have to, and that's turning many people into cynics."[9] Is the next generation to be the ones who feel deceived when the system does not work for them the way it was "supposed" to? This is a question of expectations. A recent survey of young physics faculty at all 175 physics Ph.D.-granting universities in the United States (conducted by the American Physical Society) adds another perspective to gauging the plight of the young investigator.[10] In 1990,70 percent of the young physics faculty reported that research funding is inadequate, whereas in 1977 less than 25 percent responded similarly. Of the 1990 young Ph.D. faculty who submitted ''start-up' (i.e., their first) proposals, condensed matter physicists submitted the largest average number of proposals (over five), and experienced the lowest success rates (25 percent). All other subfields had success rates from 38 to 55 percent.[11]

The report concludes that ". . . . there has been a major change for the worse in the research climate. " For condensed matter physicists, most of whom consider NSF the dominant source of support, this may be true. But the perceptions do not generalize across all subfields. Indeed, both 1977 and 1990 young physics faculty overwhelmingly ''would recommend physics' and would choose to pursue a career in physics again. In addition, twice the proportion of 1977 young faculty claimed that the ''job market was worse than expected' than reported by the 1990 young faculty (61 percent to 31 percent) .12

The merits of additional support to young investigators cannot be overstated. How this is to be achieved poses formidable challenges to research agencies and program managers, as well as to the scientific community. All contribute to the expectations and the standards for measuring the research performance of new Ph.D. s. For those young investigators who embark on academic research careers, the prospect of a FIRST, PYI, or Research Initiation award is vital if they are to become senior researchers. NIH and NSF face choices, too, in shaping researchers' expectations. These choices might include:

- limiting the amount of Federal funding that goes to one principal investigator, taking into account all sources of Federal research funds and cost differences among fields;
- addressing policies at some universities that prohibit nonfaculty personnel from applying for Federal research funds as principal investigators, and encouraging these universities to lift such bans;
- requiring the sharing of doctoral students and instrumentation; and
- encouraging universities to restrict the number of refereed publications considered for promotion, tenure, and other awards (to decrease the amounts of Federal funding required to publish longer lists of research papers) .13

9 Palca, op. cit., footnote 7, pp. 352-353.

10 The questionnaire was circulated to 939 physicists who earned a Ph.D. degree in 1980 or later and then received academi"c appointments. The response rate was 71 percent. See Roman Czujko et al., *Their Most Productive Years,* Report on the 1990 Survey of Young Physics Faculty (Washington, DC: American Physical Society, 1991) (reprinted in *Physics Today*, February *1991,* pp. 37-42).

11 Condensed matter physicists represented the largest subfield (one-third of the total respondents) in the 1990 sample. Ibid., table 3.

12 Ibid., table 5.

13 For discussion of these and other ideas, see Institute of Medicine, *Funding Health Sciences Research: A Strategy To Restore Balance* (Washington, DC: National Academy Press, November 1990). For insight into the contentiousness that greeted the institute of Medicine report, see Peter G. Gosselin, ''A Clash of Scientific Titans: Key Groups Battle Over Funds for Medical Projects, ' *The Washington Post*, Health section, Dec. 18/25, 1990, p. 6.

managers and would further serve to keep agencies alert to problems in the process of research performance.[42] Filling information gaps in the Federal support structure and creating policy-useful indicators and evaluations could assist policy formulation by both the legislative and executive branches and

42 Trend data are desirable because they reveal the early signals of flagging or surging health in one area or another. Because what is being measured is changing over time, such trends are open to interpretation. In short, interpretation must keep apace of growing sophistication in measurement. This and not the data alone becomes information for decisionmaking. See, for example, Ciba Foundation, The *Evaluation of Scientific Research* (New York, NY: John Wiley & SonS, 1989); Computer Horizons, Inc., "An Assessment of the Factors Affecting Critical Cancer Research Findings, " executive summary, NIH Evaluation Project No. 83-304, Sept. 30, 1987; and U.S. Congress, Office of Technology Assessment, *Research Funding as an* Investment: *Can We Measure the* Returns? OTA-SET-TM-36 (Washington, DC: U.S. Government Printing Office, April 1986).

help to inform decisionmakers about the effects of a changing research economy on research priorities, expenditures, and performers. Information, however, is not cost-free. Additional funding both for agency data collection and analysis, and extramural ''research on research, ' may be a necessary investment in the Federal research system of the 1990s.

In the chapters that follow, OTA delineates the participants and their roles in the research system. After introducing this decentralized system—how the executive and legislative branches negotiate national goals and the Federal budget, and how the agencies determine the allocation of research funds-OTA assesses the challenges to managing federally funded research.