Trends in Federal Support of Research and Graduate Education

Executive Summary

Board on Science, Technology, and Economic Policy
National Research Council

This report updates and extends a 1999 study of trends in federal research funding, commissioned by the National Academies' Board on Science, Technology, and Economic Policy (STEP).[1] Analysis of more recent data supports that study's principal conclusion that a substantial shift has been occurring in the composition of the federal research portfolio. This shift in funding is affecting both the allocation of resources by research field and the supply of human resources. In particular, there has been a significant reduction in federal funding for research in certain of the physical science and engineering fields. These include fields whose earlier advances contributed to the surge in productivity and economic growth of the late 1990s[2] and fields that underlie progress in energy production and conservation, pollution abatement, medical diagnosis and treatment, and other national priorities.

BACKGROUND

In the early 1990s shifting national priorities stemming from the end of the Cold War and a political consensus to eliminate the federal budget deficit began to reduce federal funding of research and development in real terms.[3] Defense R&D, funded mostly by the Department of Defense (DOD) but also by the Department of Energy (DOE), was most affected by the cuts. The purpose of the STEP Board's 1999 study was to see if, in fact, longer range research in disciplines that received most of their federal funding from DOD and other agencies with reduced R&D budgets was being cut accordingly. The study analyzed data on actual federal obligations for basic and applied research from FY 1990 through FY 1997 (the last year for which data were available), especially trends after 1993 (the last year of real growth in federal research budgets until 1998).[4]

The study showed that in 1997, although the level of federal research spending was nearly the same as it had been in 1993, a number of agencies were spending less on research than they had in 1993, including DOD (–27.5 percent), Department of the Interior (–13.3 percent), Department of Agriculture (–6.2 percent), and DOE (–5.2 percent).[5] Meanwhile, the research budget of the National Institutes of Health (NIH) had increased by 11 percent. The cuts disproportionately affected most fields in the physical sciences (physics, chemistry, and geology), engineering (chemical, civil, electrical, and mechanical), and mathematics because those fields received most of their support from agencies with reduced research funding and only a few were able to obtain increased support from other agencies. Nevertheless, the funding of particular fields frequently did not mirror the budgets of their principal supporting agencies. Some of these fields were subject to reductions in support by agencies with growing budgets. Based on these findings, the Board expressed its concern about the long-term implications of reduced federal investment in fields important to such industries as electronics, software, and materials processing and to advances in the life sciences.

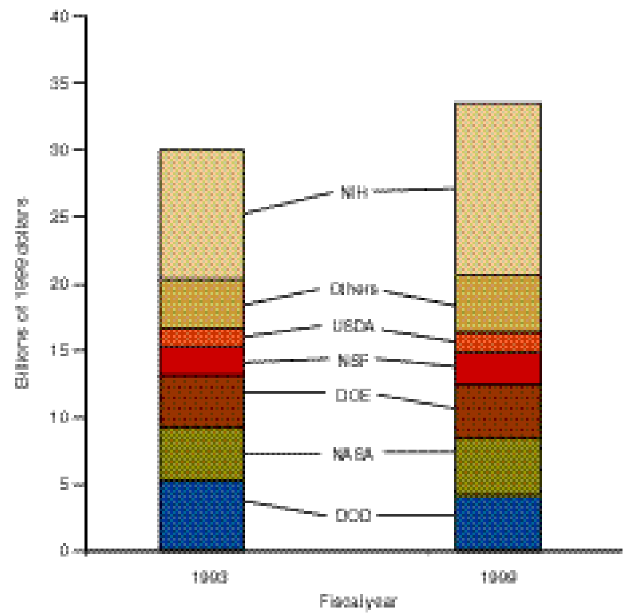


Figure ES-1. Federal funding of research, by agency, FY 1993 and FY 1999.

KEY FINDINGS

The following findings form the basis for the conclusions and recommendations of this study:

- Federal research funding in the aggregate turned a corner in FY 1998 after five years of stagnation. Total

[1] Michael McGeary and Stephen A. Merrill, "Recent Trends in Federal Spending on Scientific and Engineering Research: Impacts on Research Fields and Graduate Training," Appendix A in the following: National Research Council. 1999. *Securing America's Industrial Strength*. Washington, D.C.: National Academy Press.

2 Dale Jorgenson, "Information Technology and the U.S. Economy," *American Economic Review* 91(1):1-32 (2001) and Kevin J. Stiroh, "Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?" Staff Report, Federal Reserve Bank of New York, no. 95 (2001). Available online at: http://www.ny.frb.org/rmaghome/staff_rp/2001/2001.html

[3] Unless otherwise specified, all funding numbers in this report have been converted to constant (1999) dollars using GDP deflators (Table 10-1) in the following: Office of Management and Budget. 2001. *Historical Tables, Budget of the United States Government, Fiscal Year 2002*. Washington, D.C.: U.S. Government Printing Office.

[4] Obligations are commitments to spend money, regardless of when the funds were appropriated and of whether actual payment is made later, for example, under multi-year contracts. The data on federal obligations are based on the federal fiscal year, which begins October 1 each year. Data on expenditures by other sponsors of research are for calendar years.

[5] McGeary and Merrill, *op cit.*, Table A-1.

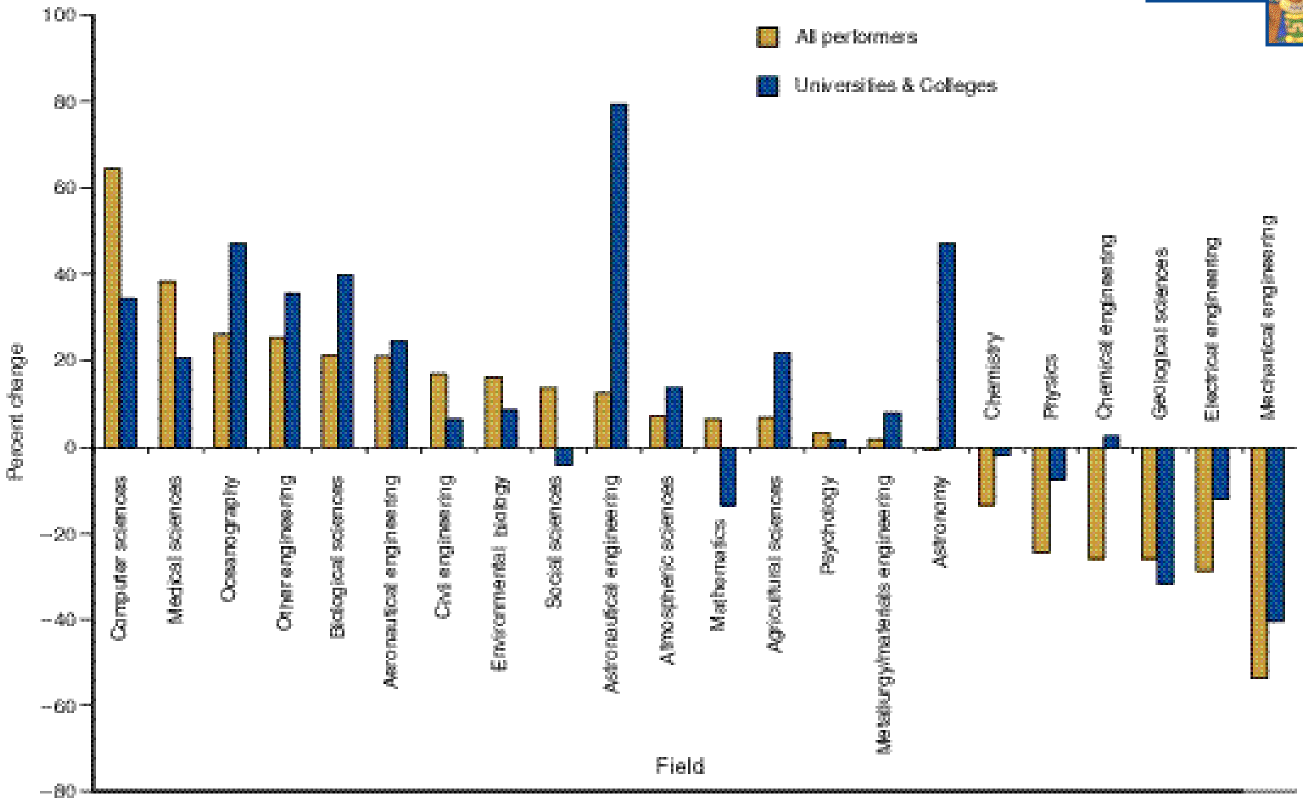


Figure ES-2. Changes in federal research obligations for all performers and university/college performers, FY 1993-1999.

expenditures were up 4.5 percent in FY 1998 over their level in 1993. A year later, in FY 1999, they were up 11.7 percent over 1993. FY 2000 and FY 2001 saw continued growth in budget authority for research. These increases are accounted for primarily by NIH. Indeed, increases in NIH appropriations kept federal research funding from falling even lower in the mid-1990s and have dominated more recent growth in overall research funding (see Fig. ES-1). Moreover, NIH is slated by the current administration for substantial increases in the next several years while most other agencies would receive flat or reduced funding for research.

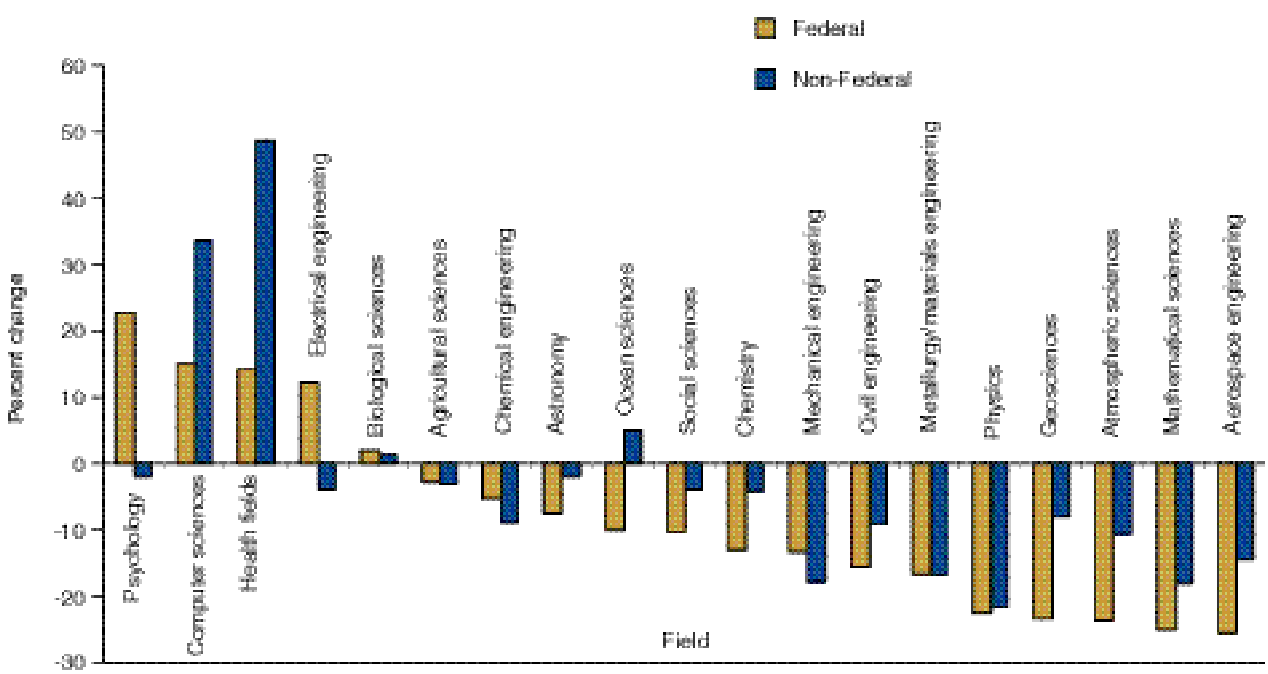
- Although federal research funding began to increase after 1997, the new composition of federal support remained relatively unchanged. In 1999, the life sciences had 46 percent of federal funding for research, compared with 40 percent in 1993. During the same period, physical science and engineering funding went from 37 to 31 percent of the research portfolio.
  - Whereas 12 of the 22 fields examined had suffered a real loss of support in the mid-1990s (four by 20 percent or more), by FY 1999 the number of fields with reduced support was seven. However, five of these—physics, geological sciences, and chemical, electrical, and mechanical engineering—were down 20 percent or more from 1993.
  - The fields of chemical and mechanical engineering and geological sciences had less funding in 1999 than in 1997. Funding of some fields—including electrical engineering and physics—improved somewhat from 1997 to 1999 but not enough to raise them back up to their 1993 levels.
  - Other fields that failed to increase or had less funding after 1997 included astronomy, chemistry, and atmospheric sciences.
  - One field that had increased funding in the mid-1990s, materials engineering, experienced declining support at the end of the decade. Its funding was 14.0 percent larger in 1997 than in 1993, but that margin fell to 3.0 percent in 1998 and 1.5 percent in 1999.
  - The fields whose support was up in 1997 and has continued to increase include aeronautical, astronautical, civil, and other engineering;[6] biological and medical sciences; computer sciences; and oceanography.
  - Fields that, like overall research expenditures, turned a corner were environmental biology, agricultural sciences, mathematics, social sciences, and psychology.

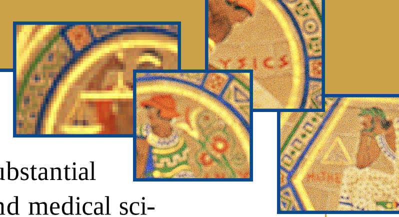
[6] Other engineering includes agricultural, bioengineering, biomedical, industrial and management, nuclear, ocean, and systems engineering.

Their funding, which was less in 1997 than in 1993, exceeded the 1993 level by 1999 (see Fig. ES-2).

- More recent actions on federal budgets for research, including the first installments in doubling of the NIH budget over the 5 years ending in FY 2003, will increase the current divergence between the life sciences and other fields unless other fields receive substantially larger increases than proposed.
- The decline in the support of many of the physical science and engineering fields is partly attributable to the fact that the budgets of their principal sponsoring agencies (e.g., DOD, DOE, and the National Aeronautics and Space Administration [NASA]) did not fare as well as the NIH budget and partly to the fact that the agencies with growing budgets, especially NIH and the National Science Foundation (NSF), did not increase their support of those fields and in some cases reduced it. At the same time, some fields—e.g., computer sciences, oceanography, and aeronautical engineering—experienced substantial growth even though their largest 1993 funders were agencies with shrinking budgets—e.g., DOD and NASA. These fields did so by maintaining their level of funding from agencies with declining budgets and by picking up additional support from other agencies.
- The patterns in federal funding of basic research and research performed at universities are similar to that for overall funding of research but somewhat more favorable, suggesting that by the late 1990s agencies were tending to protect basic and university research relative to applied research and other performers.
- Although federal funding of research assistant positions through research grants and contracts is but one factor among many in determining the number of graduate students in training and the number of Ph.D.'s produced in a field, graduate enrollments and Ph.D. production were generally down in fields that had less federal funding in 1999 than in 1993. Over the next few years, these declines will contribute to an ongoing reduction in the supply of new talent for positions in governmental/nonprofit organizations, industry, academia, and other employment sectors (see Fig. ES-3).
- Although the data are much more limited, it appears that states and philanthropies have shared the research priorities of the federal government in the last decade. For both states and foundations, biomedical research consumes a majority of research funding and has grown at a faster rate than support of other scientific and engineering fields.
- Data on the composition of industry-funded research are classified by sector rather than by field and thus are not directly comparable to those on federal expenditures. The data show that corporations' spending on research has been increasing but is concentrated in a few sectors such as the pharmaceutical industry and the

Figure ES-3. Changes in full-time graduate enrollment, by field and primary source of support, 1993-1999.





information technology sector. Electronic components was one industry in which research investment increased as federal support of the most closely related research field, electrical engineering, declined over the decade. Nevertheless, except for a few industries such as pharmaceuticals, only a small fraction (less than 5 percent in computers and semiconductors, for example) of all corporate research and development is basic research. Moreover, private research investment is quite volatile, sometimes subject to wide fluctuation from year to year with or independent of the business cycle.

- The shifts in federal funding of fields were partly the result of congressional (e.g., biomedical research) and presidential priorities (e.g., high-performance computing research and development); but the funding reductions were substantially the product of decentralized decision making by officials in various departments, agencies, and congressional committees, adjusting resources to agency mission needs in a constrained budget environment. Impacts on the overall composition of the federal research portfolio were not considered until FY 2000, when the administration and Congress began to discuss the balance of funding among fields, and the FY 2001 budget cycle, when for the first time balance became an explicit criterion used by the administration in developing its budget request.

CONCLUSIONS

The recent shift in composition of the federal research portfolio is significant. Although nonfederal entities increased their share of national funding for R&D from 60 to 74 percent between 1990 and 2000, federal funding still supports a substantial component, 27 percent, of the nation's total research expenditures, 49 percent of basic research spending. Reductions in federal funding of a field of 20 percent or more have a substantial impact unless there are compensating increases in funding from nonfederal sources, which does not appear to be the case in the last few years. Generally speaking, moreover, federal funding for research has a longer time horizon and can be more stable than investments from other sources.

The funding trends leading to shifts in the federal research portfolio will continue under the administration's budget plan. The administration's request for NIH for FY 2002 would increase its budget authority for research by 12.9 percent over the 2001 level in constant dollars. All other non-defense research would be reduced by 1.5 percent. There is also provision for an increase in DOD's budget authority for research but its allocation awaits the results of the administration's strategic review. There is little indication, based on their portfolios from 1993 to 1999, that NIH would allocate substantial funds to fields outside of the biological and medical sciences or that DOD would rebuild funding for fields the department previously cut or increased less. NSF, with the broadest research portfolio, has tended to increase its support of fields whose funding from other sources is growing and reduce support of some fields whose support is declining elsewhere. In any case, its research budget is small compared with those of DOD and NIH.

There are compelling reasons for the federal government to invest across the range of scientific and engineering disciplines.[7] Increasingly, the most important problems in both the life and physical sciences and engineering require collaboration across disciplines. Examples include genomics and bioinformatics, which rely on mathematics and computer science as much as biology for progress; nanotechnology, which depends on chemistry and chemical engineering, physics, materials science and technology, and electrical engineering; and understanding of climate change, which relies on collaboration among oceanographers, atmospheric chemists, geologists and geophysicists, paleontologists, and computer scientists.

Furthermore, research, by its nature, is highly uncertain. It is not possible to know when and where breakthroughs will occur, what practical applications they may have, and when those applications may pay off. Important advances in one field sometimes come from apparently unrelated work in another field. For example, who knew in 1945 that the discovery of nuclear magnetic resonance in condensed matter by basic research physicists would lead to the development of MRI technology 30 years later?[8] Increasing interdisciplinarity and uncertainty about where advances will take place and if or when they will be commercially successful argue for the prudence of investing in a broad portfolio of research activities.

There is cause for concern about the allocation of funding among fields in the federal research portfolio, in particular with respect to most of the physical sciences and engineering whose funding, in contrast with the biomedical sciences, has with few exceptions stagnated or declined. The current level of funding in some fields may not be optimal from a national perspective or from the

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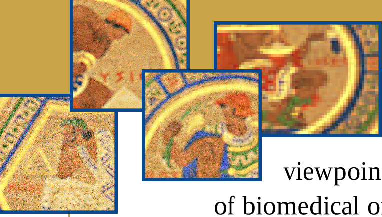
[7] The rationale for a diverse portfolio is articulated by the Committee on Science, Engineering, and Public Policy in the following: National Academy of Sciences, National Academy of Engineering, Institute of Medicine. 1993. *Science, Technology, and the Federal Government: National Goals for a New Era*. Washington, D.C.: National Academy Press; and National Research Council. 1995. *Allocating Federal Funds for Science and Technology*. Washington, D.C.: National Academy Press.

8 National Academy of Sciences. 2001. *A Life-Saving Window on the Mind and Body: The Development of Magnetic Resonance Imaging*. (March issue). Washington, D.C.: National Academy Press. At: www/b eyonddiscovery.org/beyond/BeyondDiscovery.nsf/ files/PDF MRI.pdf/$file/MRI PDF.pdf.



viewpoint of those who support expanded funding of biomedical or computer science research. Advances in both of the latter fields will be dependent on progress in a broad range of fields of fundamental research, including physics, chemistry, electrical engineering, and chemical engineering, all fields with less funding at the end of the 1990s than they received earlier in the decade.

Although it may be wise policy to reduce the linkage between research funding and training support,[9] research allocation decisions should take into account the need for trained people in a field. Curtailing research in a field may constrict the supply of trained people with advanced technical degrees (not only Ph.D.'s) who are capable of applying and exploiting research advances in a variety of settings including but not limited to the laboratory. Increasingly, there is a premium on scientific and engineering training in a range of service as well as manufacturing industries. The effect of cutting research is both direct, in reducing the number of research assistant positions, and indirect, in signaling to prospective graduate students that some fields offer poor career opportunities.

The current system for allocating research funding does not necessarily ensure that national priorities are taken into account. In the highly decentralized U.S. system of support for science and engineering, most research funding is tied to the missions of federal agencies rather than national needs more broadly conceived, such as technological innovation and economic growth. If a mission changes—for example, defense strategy in the post-Cold War world—support of certain fields of research may decline for reasons that are entirely defensible in terms of the affected agency's priorities but not necessarily defensible in terms of the research opportunities in and productivity of those fields and their potential contributions to other national goals.

The evidence of changing agency priorities and portfolios is actually encouraging. In a rapidly changing world, it would be disturbing if spending patterns were static. But there is no process for reviewing systematically the effects of these decentralized decisions on the health of research fields and the supply of human resources with reference to a set of national goals. It may be that funding reductions are entirely warranted by diminished research opportunities or productivity or less need for people in those specialties. On the other hand, funding increments may be justified. Simply increasing the research funding of certain agencies (for example, DOD, DOE, or NSF) will not necessarily achieve the desired allocation by itself. A single agency's research budget may be comparatively small and widely dispersed or the agency may continue to allocate any increases to its current priorities. The task requires some centralized oversight, similar to the mechanisms for advancing presidential priorities that cut across agency programs and budgets.[10]

RECOMMENDATIONS

Based on these conclusions, the committee recommends action in three areas. For the most part our recommendations reaffirm previous Academy statements on the budget allocation process for research,[11] priorities for the National Science Foundation's statistical arm, the Division of Science Resources Studies,[12] international benchmarking of scientific performance,[13] and federal support of graduate training in science and engineering.[14]

Evaluation and Adjustment of the Research Portfolio

The U.S. system for funding and performing research has many strengths and accounts in large part for the productivity of American science and technology. In making the following recommendations, we are not calling for centralization of decision making about research priorities and spending. What is needed is a mechanism or mechanisms to monitor the aggregate results of a very decentralized system of selecting and carrying out research projects to see if adjustments are needed to close gaps or reduce shortfalls that occur when policy makers make decisions in a narrow framework.

> Recommendation 1. The White House Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB), with assistance from federal agencies and appropriate advisory bodies, should evaluate the federal research portfolio, with an

[9] A position taken by the Committee on Science, Engineering, and Public Policy in the following: National Academy of Sciences, National Academy of Engineering, Institute of Medicine. 1995. *Reshaping the Graduate Education of Scientists and Engineers*. Washington, D.C.: National Academy Press.

[10] National Science Board, "The Scientific Allocation of Scientific Resources" [Discussion Draft for Comment], March 28, 2001, p. 3.

11 National Research Council. 1995. *Allocating Federal Funds for Science and Technology*. Washington, D.C.: National Academy Press.

12 National Research Council. 2000. *Measuring the Science and Engineering Enterprise*. Washington, D.C.: National Academy Press; and National Research Council. 1997. *Industrial Research and Innovation Indicators*. Washington, D.C.: National Academy Press.

13 National Academy of Sciences, National Academy of Engineering, Institute of Medicine. 2000. *Experiments in International Benchmarking of U.S. Research Fields* Washington, D.C.: National Academy Press.

14 National Academy of Sciences, National Academy of Engineering, Institute of Medicine. 1995. *Reshaping the Graduate Education of Scientists and Engineers*. Washington, D.C.: National Academy Press.

initial focus on fields related to industrial performance and other national priorities and a recent history of declining funding. Examples are physics, electrical engineering, chemistry, chemical engineering, mechanical engineering, and geological sciences. Fields with flat funding or only small real increases through the 1990s also merit attention. These include materials engineering, atmospheric sciences, mathematics, psychology, and astronomy. The conclusions of the evaluation should be reflected in budget allocations.

Recommendation 2. Congress should conduct its own evaluation of the federal research portfolio through the budget, appropriations, or authorization committees.

Recommendation 3. For the longer term, the executive branch and Congress should sponsor the following types of studies: (1) in-depth qualitative case studies of selected fields, taking into account not only funding trends across federal agencies and nonfederal supporters and international comparisons but also subtler differences in the foci, time horizons, and other research characteristics that are obscured by quantitative data; (2) studies of agency research portfolios and decision making to understand the reasons for shifts in funding by field and the extent to which the health of individual fields and interrelationships among fields are taken into account; and (3) studies of methodologies for allocating federal research funding according to national rather than merely departmental criteria and priorities.

Recommendation 4. The executive branch and Congress should institutionalize processes for conducting and, if necessary, acting on an integrated analysis of the federal budget for research by field as well as by agency, national purpose, and other perspectives.

Data Improvements

National data systems need to be expanded and improved to support better policy making.

Recommendation 5. NSF should annually report and interpret data from its survey of federal R&D obligations in a form (e.g., adjusted for inflation) and on a schedule useful to policy makers. Improvements in the data that should be given careful consideration include obtaining data by field on performers other than universities (e.g., in industry and government laboratories), evaluating and revising the field classification, and making the field classification and research typology uniform across surveys (e.g., the surveys of academic R&D expenditures and earned doctorates as well as the survey of federal R&D obligations). Agencies should make sure that the data they provide NSF are accurate and timely.

Recommendation 6. Although it may be impractical to obtain data on industrial R&D spending by research field, NSF should administer the Industrial R&D survey at the business unit level to make data on the composition of private R&D more meaningful.

Recommendation 7. NSF should consider ways of obtaining data on the allocation of state expenditures on a regular basis.

Recommendation 8. The philanthropic community should cooperate in collecting and publishing data on contributions to research on a basis comparable to federal research statistics.

Analytical Improvements

The analysis presented here, a gathering of existing data from various sources, is a first step that raises more questions than it answers.

Recommendation 9. NSF and other federal agencies funding research should support benchmarking studies that compare inputs and outputs across countries and sponsor other efforts to develop techniques for assessing the productivity of various fields of research.

Recommendation 10. NSF should continue and expand its efforts to develop innovation indicators other than R&D expenditure inputs, collect data on them, and fund researchers to analyze them. Other agencies (e.g., NASA, DOD, DOE, and the National Institute of Standards and Technology [NIST]) interested in the role of federal research in technological innovation could fund or jointly fund such analyses.

Recommendation 11. Researchers, professional societies, industry associations, and federal research agencies should explore the relationships between federal research funding and other factors (e.g., population flows through the educational system, domestic and foreign student demand, labor market conditions, etc.) in the development and use of scientific and engineering talent. Only then can we evaluate the trends in student enrollment and in graduate study programs' output and determine how to influence those trends if that is the conclusion of the analysis.

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