SCIENCE AND TECHNOLOGY POLICY: PAST AND PROLOGUE

A Companion to *Science and Engineering Indicators—2000*

National Science Foundation

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I. Introduction

Every two years, the National Science Board[*] produces *Science and Engineering Indicators*, a quantitative overview of the U.S. science and technology (S&T) enterprise. Publication of *Science and Engineering Indicators—2000* coincides with the 50th anniversary of the creation of the National Science Foundation (NSF) in 1950. As NSF and the National Science Board prepare to embark on their second half-century, the Board believes it is useful to reflect on the conditions that characterized U.S. science and engineering 50 years ago, on accomplishments and changes, and on directions for the future of the enterprise.

In taking stock of the impacts of science and technology, the Board is moved to comment on the role of policy in S&T – how it is shaped by data, information, and analysis. The process of making choices constitutes the heart of policymaking – determining priorities and investment levels, nurturing long-standing programs, and responding appropriately to emerging research opportunities. Any retelling of U.S. achievements in science and engineering must include policy as "organizing principles" and the arrangements for pursuing them. Together they create the prospects for discovery and application. Inevitably, S&T are among the factors tied to choices made in the strategic allocation of scarce resources.[1]

II. A Record of Discovery in Science and Technology

> "Even economics, in this age of a booming economy, cannot rival the appeal of science and technology as the driving force of history."
>
> *Gertrude Himmelfarb*[2]

A record of research discoveries in science and engineering stands as a legacy of Federal contributions to the life, health, security, and enlightenment of the U.S. citizenry. The innovations driving our economic prosperity have emerged, often unpredictably, from a bedrock of national investments in fundamental research made in years past. The Council on Competitiveness, the U.S. Chamber of Commerce, and the Federal Reserve Board last year all cited S&T research as good for business.[3] Evidence mounts that research is a major contributor to U.S. productivity.

In 1971, the first commercial microprocessor was manufactured. Fourteen years later, *Indicators* highlighted instrumentation for advancing knowledge in science and engineering – spectroscopy, lasers, superconductivity, and monoclonal antibodies.[4] Since then, discoveries, techniques, and refinements abound: materials such as synthetic polymers are used in products ranging from clothing to cars; tools such as the Hubbell and Gemini telescopes explore even beyond our solar system; particle beams probe the structure of matter at distance scales 100 billion times smaller than the size of an atom; and mathematical modeling helps us predict the probability of earthquakes and long-term weather phenomena such as El Nino, test ideas of the nature of matter, study traffic patterns and brain function, and assess economic and health risks.

A human resource base developed in our institutions of higher learning and employed in all regions and sectors of the U.S. has grown the capacity of the Nation's research workforce. Since 1973, the number of science and engineering researchers receiving support from at least one Federal agency nearly doubled (97 percent).[5] Add to these federally funded researchers the contributions scientists and engineers make as educators, administrators, managers, and public servants, and the investment in people yields handsomely. Demand for such workers, at all degree levels, is projected to increase well beyond the rate for other occupations.[6]

The 21st century will be known for the melding of our human and science-based infrastructure. The infusion of information technology in our economy is revolutionizing communication as embodied in the Internet and "e-commerce," shrinking the world, creating wealth, and transforming daily routines.

Such impressive research-based capabilities are juxtaposed against a troubling reality: For more than two decades, surveys have shown that American adults have a high level of interest in scientific discoveries, new inventions, and technologies.[7] Three of four perceive the benefits of scientific research to outweigh its potential harm. But no more than one in five Americans either comprehend or appreciate the value and process of scientific inquiry. While the public's confidence in science is high, for many it is a blind trust. Americans are deeply divided over the development and impact of several important technologies, some of which are discussed below.

The progress of S&T demands more of each of us. One peril is that technical virtuosity distances what most can observe from what a few specially equipped and trained can see and manipulate. Even if we are motivated to understand the implications of new knowledge, this requires more plain talk about risks as well as benefits and better explanations of why the latest breakthrough matters.[8] Before citizens will embrace yet another marvel intended to ease, remedy, or otherwise improve life, they deserve information that will inform their thinking.

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[*] The National Science Board (NSB) consists of 24 members plus the Director of the National Science Foundation. Appointed by the President, the Board serves as the governing body for NSF and provides advice to the President and the Congress on matters of national science and engineering policy.

III. Opportunities for the Ages

> "The coming century will impose greater demands and responsibilities on all who have a stake in the discovery and use of knowledge."
>
> *National Science Board* [9]

The quest to understand the nature of the atom in the early twentieth century led to a scientific revolution. In overturning conventional thinking, quantum mechanics was discovered. To test this theory, microscopes were devised to study phenomena at scales of atomic size and smaller – much smaller than what is readily observable.[10]

In this age of S&T, the challenge to scientists, engineers, and policymakers alike is to generate new ideas and tools that harness research-based knowledge in the fight against human disease and disability, preserve the natural environment, enhance the quality of life, and assure a robust public investment in science and technology. As fields of science, mathematics, and engineering continue to specialize, overarching research themes cross disciplines and, moreover, captivate the public as issues of health, environment, energy, and space.

Areas such as genetics/biotechnology and information technology/telecommunications hold special promise. They are ripe for exploitation because of scientific discoveries made in past centuries and 20th century tools that enable discovery and advance knowledge. For example, the Human Genome Project, launched in 1990 as a distributed "big science" initiative, has historical roots in the Watson-Crick discovery in 1953 of a double helical structure of the DNA molecule, and the first recombinant DNA techniques (or gene splicing) pioneered by Hamilton Smith and Daniel Nathans in the 1970s. A quarter-century later, Ian Wilmut and Keith Campbell cloned a sheep from adult cells.[11]

Today, the research environment includes a host of normative ("should we do it?") questions that surround technical capability ("we can do it") with public controversy.[12] For all the inevitable apprehension about the unknown, a newer age of life-enhancing innovations is not far off – biomonitoring devices that provide accurate readouts of our health and sensory prosthetics that synthesize speech, computerize vision, and feed electronic waves directly into the brain.[13]

A separate stream of inquiry in information technology has borne remarkable fruit. The U.S. Department of Defense's Advanced Research Projects Agency created ARPAnet, the precursor to the Internet, to facilitate communication among researchers. The National Science Foundation provided the critical sustenance that delivered this tool to university researchers. Subsequently, the World Wide Web was created to promote rapid data sharing among large collaborations of high energy physicists, a development that both simplified and popularized navigation on the Net. "The idea that anyone in the world can publish information and have it instantly available to anyone else in the world created a revolution that will rank with Gutenberg's . . . .[14]

The need to store, share, and interpret vast amounts of data[15] has engendered whole new subfields, such as bioinformatics, which is dedicated to applying information technology (IT) to the understanding of biological systems. To explore the interdependencies among the elements of specific environmental systems will require the development of software, human-computer interaction and information management, and high-end computing. Companies use information technology to compete in today's global marketplace by tailoring their products and services to the needs of individual customers, forging closer relationships with their suppliers, and delivering just-in-time training to their employees. If we are to understand and deal with the socioeconomic, ethical, legal, and workforce implications of these systems, we will need to support a research agenda that crosses disciplines, languages, and cultures.

Highlighting technologies that are likely to blossom in the 21st century recalls yesterday's basic research. History instructs that we cannot predict *which* discoveries or technologies will change the lives of future generations. Rather, fundamental science and engineering research presents long-term opportunities – a high-risk investment with high payoffs.

IV. The Role of Policy

> ". . . each new branch of science can open wondrous new opportunities while posing societal challenges that will require vigilance and insightful management."
>
> *Floyd Bloom*[16]

The future of science and technology will require more wise policy decisions about how to use the Nation's resources to the greatest benefit. Policy is a management tool for nurturing, distributing, and harvesting the creativity of S&T. In choices made daily by decisionmakers in the public and private sectors, Federal policy clasps the invisible hand of the market. The result is an evolving research economy in science and engineering that continues to spur intellectual endeavor, increase participation by those talented and trained, and capture innovations for the public good.

Origins. The progress of science and technology appears so inevitable that the role of policy choices is not often highlighted. Knowledge may appear to unfold in a "natural" course, but sponsorship, and increasingly stewardship, have played a key role in the 20th century.

With the passage of time, early visions of science for society have come to embody a set of national values and objectives that provide a framework for policy development.[17] Two key policy documents are virtually synonymous with these values: Vannevar Bush's "Report to the President on a Program for Postwar Scientific Research" (subsequently known as *Science—the Endless Frontier*, July 1945), and *Science and Public Policy* (the "Steelman Report," August 1947). Each report emphasized the bipartisan nature of Federal funding for science and established a core principle that remains among the strengths of the U.S. research system: a strong commitment to partnerships, especially those rooted in the exchange of Federal support of research in universities for the production of knowledge, innovation, and trained personnel for the Nation's workforce.

The Bush Report was not a science policy blueprint. However, it contained the seeds of ideas that have come to be known as "policy-for-science" – issues focused on funding levels, sources, incentives, and priorities for research, and the development and utilization of human resources for science and engineering. In contrast, the Steelman Report encompassed "science-for-policy" issues concerned with the uses of scientific knowledge and capabilities for governance and in the service of the larger society.

The first summary volume of *Science and Public Policy* employed 10-year projections to support recommendations about the resources required to assist the U.S. science and engineering enterprise in addressing national objectives. Significantly, one projection called for a doubling of national R&D expenditures during the succeeding 10 years.[18] This was before the launch of Sputnik and the National Defense Education Act of 1958, which accelerated a rising national consciousness about S&T careers and science education and ratcheted up the Federal R&D budget.

Revisiting the Origins. As the 20th century came to a close, the United States faced the novel challenge of redefining its goals and priorities in the post-Cold War era. While the importance of science and engineering to the Nation was unquestioned, a clear and uncomplicated rationale rivaling "national security" was lacking. When the "balanced budget" became an overriding priority by 1995, competition for scarce resources grew fierce among claimants to the "discretionary" budget. Long-term investments such as R&D were decidedly vulnerable.

By the mid-1990s, two major Federal policy reports sought to reexamine science policy in a changing economic, political and social context. Both emphasized science in service to society while reaffirming a commitment to university-based research and improved science and mathematics education. The 1994 Clinton-Gore blueprint, *Science in the National Interest*, reiterated the core values that have enabled the Nation to achieve so much through fundamental science – the strength of investigator-initiated research and merit review by expert peers. The report suggested a framework for national science policy organized around five goals deemed essential for the U.S. scientific and engineering enterprise: leadership across the frontiers of scientific knowledge; connections between fundamental research and national goals; partnerships that promote investments in fundamental science and engineering and effective use of physical, human and financial resources; the finest scientists and engineers for the twenty-first century; and scientific and technological literacy of all Americans.[19]

A congressional perspective came in the form of a special study in 1998 by the House Committee on Science led by Congressman Vernon Ehlers. *Unlocking Our Future: Toward a New National Science Policy* noted that the scientific enterprise needed to "ensure that the well of scientific discovery does not run dry . . . ," that "discoveries from this well must be drawn continually and applied to the development of new products or processes . . . ," adding that "education . . . [produces] the diverse array of people who draw from and replenish the well of discovery . . ." and amplifies "the lines of communication between scientists and engineers and the American people."[20]

Both reports employed a participatory process, increasing the credibility of subsequent decisionmaking and asserting a continuity of organizing principles tempered by new economic realities: university-based research in a global context; partnerships across disciplines, organizations, and sectors; and public accountability. Each report also acknowledged the indispensability of Federal research investments in a 21st century S&T enterprise shaped by information technology and attuned to societal needs. Predicting that a broad bipartisan consensus would likely continue, the reports warned of funding constraints and the need to establish priorities for Federal support and demonstrate contributions to attaining societal goals.

Finally, like Bush and Steelman, both reports assigned a high priority to human resources as an integral element of science policy. Cultivating an increasingly diverse student body to renew the workforce of a global economy requires quality science education at the K-12 level. Our education system could serve more students far better than it does, especially those in urban and rural areas born into disadvantage. High standards, expectations, and accountability alone cannot rescue schools lacking the resources to support mathematics and science learning to prepare students for the 21st century workforce. This demands well-trained, -equipped, and -rewarded teachers.[21]

Visionary Federal documents issued a half-century apart attest to a consistency of values. The mingling of curiosity and opportunity, largely undirected and fostered in a climate of open exchange, has produced an unparalleled national record of performance and progress in knowledge and innovation.

This legacy has also yielded an irony – times may change, but policy issues remain much the same. Questions persist about the appropriate Federal role in funding the enterprise: How much is enough? What constitutes a strategic balance among problems, disciplines, and levels of funding? As private R&D funding accounts for two-thirds of total national R&D, are investments being skewed toward the short-term, industrial end of the research continuum?

Over 50 years ago, the Bush and the Steelman reports identified fundamental policy values: ample human resources for science and engineering, a vigorous science and engineering infrastructure for research, a robust government-university partnership to advance knowledge in conjunction with education and training, and a symbiosis between fundamental research and national goals. These values endure.

A Changing Federal Role? What, then, should be the Federal role in a global context – one in which multinational corporations influence significant parts of the Nation's research agenda? How should challenges facing society inform methodologies for priority setting in research? What mechanisms effectively build broad public and scientific support for, and involvement in, the priority setting process? Who is monitoring the incremental growth of the knowledge base and opportunities emerging at the interstices of disciplines? And what education and training are appropriate for producing versatile workers who face a growing diversity of employment prospects and careers? Whatever the responses – policies, programs, and initiatives – the Federal portfolio must be diverse, flexible, and opportunistic, drawing on the creative strengths of many fields and employing a range of organizational strategies.

While individual serendipity – an aspect of organized science for over 300 years – and collaborations among scientists and engineers (virtually if not physically) grow, the S&T enterprise must adapt to the exigencies imposed by scale, resources, and organizational complexity. Planning and coordination among partners within a framework that is explicitly global must promote collaboration without diminishing the system's competitive energy. An overarching goal is developing strategies to enhance global scientific communication, international exchanges of students and technical personnel, and databases to sustain research and discovery in the international arena.[22]

A sequence of sage decisions made over an expansive period of science and technology has brought us to this point. That is the resounding message of the Federal science policy reports of the last half-century. The current generation of stewards must apply the same ingenuity to endow our social structures with the wisdom of experience and the tools of analysis. This legacy guides the National Science Board in promoting and anticipating the needs of S&T as an institution.[23]

Science and Engineering Indicators—2000, like the volumes that have preceded it, can be an anchor for policymakers awash in information and contradictory claims. Just as we accumulate systematic knowledge about the enterprise, *Indicators* should illuminate signposts to its future. By definition, indicators are retrospective and heuristic, not explanatory. In combination, they may reveal patterns or suggest relationships that call for more intensive analysis. We offer some examples below.

Investments and Returns. While the system of national support of S&T has flourished, Federal funding across disciplines has shifted. "The life sciences now account for more than 50 percent of the U.S. Federal investment in basic research . . . . Today's strong Federal support for the life sciences is warranted because biomedical research is on the cusp of a revolution in preventative medicine and treatment. Nevertheless, today's overall research budget is increasingly out of balance."[24]

When is the Federal R&D portfolio – interagency initiatives as well as agency mission-based programs – diversified too little or too much? How can we tell when basic research seems constricted relative to applied investments? How do management, regulation, and accountability foster inquiry without unduly fettering it?

What has worked in the past could shackle the future. Concern for imbalance among fields and research problems is a challenge to policymakers, as is priority setting, especially when funding lags the pace of discovery and application. R&D, after all, is one national investment among many.

Until recently, the so-called productivity paradox, captured by the maxim "computers are everywhere except the productivity statistics," dogged investments. Today, the value of information technology is no longer in doubt.[25] Experts argue that, in an $8.8 trillion knowledge-based economy, more than 2.8 percent of the Nation's GDP should be devoted to R&D. In addition, given the extraordinary contributions of fundamental research to long-term economic growth, an investment greater than the 22 percent of the total Federal R&D budget that currently goes to "basic research" seems more than justified.[26] Unsettling to many is the declining Federal share of national R&D as industry fuels technology – the promising technologies profiled above and an array of other interdisciplinary specialties.[27]

Clearly, we are more adept at measuring dollar inputs than outcomes such as peer-reviewed publications, citations, patents, and honorific awards. Capturing the full public return on investments in science and engineering research remains elusive. Yet *Indicators—2000* helps make sense of a complex enterprise.[28] Trends in knowledge production and the Federal stewardship role illustrate two classes of indicator.

Trends in the Globalization of Research. Multiple authorship of the S&T literature, citation patterns by field and country, and patents awarded provide a thumbnail sketch of the global knowledge system. Since 1986, multiple and international coauthorships are on the rise.[29] In 1997, the proportion of the world S&T literature published in major international journals accounted for by three countries – the U.S., Japan, and the U.K. – represented one-half the total. But the U.S. proportion of the world S&T literature cited from 1990 to 1997 is down in all fields, though we lead the world's research production in health and psychology. Declines in the U.S. share are marked in mathematics, biology, and engineering.[30]

In sum, the world is catching up. But one wonders whether a falling U.S. share of citations in a field should be regarded as a problem: the U.S. share of world GDP has declined significantly, much to our Nation's advantage. There are more participants in the world publication market and the leaders' share is eroding, while collaboration with researchers around the globe is becoming a routine option.

The proportion of citations on U.S. patents to the U.S. S&T literature decreased from 1987-98 in physics, chemistry, and engineering/technology. Only in biomedicine did citations to U.S. literature increase significantly in patent applications.[31] An institutional perspective on patenting signals a growth trend. But academic patents still represent only 5 percent, or more than 3000 annually, of all new U.S.-origin patent awards. This is a five-fold increase from 1985, when 111 U.S. academic institutions were awarded patents. In 1998, the number grew to a total of 173 different universities, and the top 100 patenting universities accounted for over 88 percent of all the patents awarded to academic performers.[32] Research universities have become not only incubators of innovation, but also partners in developing and commercializing products that generate income and hold value for other sectors of the Nation's economy.

Payoffs of Federal Stewardship. The Nobel Prize is the most widely-recognized honor conferred for scientific achievement.[33] For the period 1950-95, U.S. citizen and foreign scientists located in American institutions dominate the roster of Nobel laureates. *Indicators—2000* includes an appendix table that lists all Nobel laureates awarded the Prize 1950-99. Data from other agencies are not available, but information on whether the recipients received NSF funding during their career, pre- and post-Nobel, suggests the role played by Federal support in the careers of extraordinary 20th century scientists.[34]

The findings are striking. The Federal Government has a remarkable record of supporting U.S. Nobel laureates *before* bestowal of the Prize. Roughly one of three laureates in Physics and Chemistry, and two of five in Economics, successfully competed for NSF research grants. In the aggregate careers of all laureates since 1950, over 40 percent have benefited from NSF support. So while the Nobel Prize is often discounted as a measure of where science – paradigm-breaking science at that – *has been*, as opposed to where it *is going*, the Federal distribution of scarce resources to researchers has repaid the investment in their work many times over.

Taken together, these data reflect a national commitment to science and engineering research. This grand public experiment engendered fields of knowledge not easily visualized a half-century ago. Such government stewardship indicates an oft-overlooked U.S. achievement in science – underwriting risk-taking research programs and investigators long before their promise was recognized by the S&T community and hailed by the world.

V. Conclusions

> "We should also remember that, like the Internet, supercomputers and so many other scientific advances, our ability to read our genetic alphabet grew from decades of research that began with government funding. Every American . . . should be proud of their investment in this and other frontiers of science."
>
> *President William J. Clinton* [35]

Today we have the ability to manipulate individual atoms and molecules on the scale of one billionth of a meter. This poses myriad possibilities in the way most everything, from medicines to automobile tires, is designed and made.[36] By increasing the wonder of science and engineering – a computer chip millions of times as fast as today's Pentium 3 or new methods of removing the smallest contaminants from water and air – we increase hope.

Communicating how things work and why they matter is a continuing challenge. S&T cannot flourish without the visionary use of policy to communicate the joy, fascination, and utility of science and engineering. *Indicators* can tell us where we have been and suggest where we might be going.

As we celebrate the 50th anniversary of an institution called the National Science Foundation, and reflect on the creative S&T enterprise of which it is a part, we welcome the still-endless frontier that the 21st century holds. We are especially proud to assist, through *Indicators*, policymakers and government leaders whose decisions will affect the ability of science and engineering to benefit society. That would be a noble achievement beyond this jubilee year.

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EHR Subcommittee on Science & Engineering Indicators

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ENDNOTES

[1] National Science Board, *Government Funding of Scientific Research* (Arlington, VA: National Science Foundation, 1997, NSB 97-186).

[2] Gertrude Himmelfarb, "Heroes and Antiheroes Survive the Millennium's Dawn," *The Chronicle of Higher Education*, Jan. 21, 2000, p. A64.

[3] Specifically, the 2 percent per annum growth in productivity observed in the last three years doubled the pace of growth from 1973 to 1995. See Council on Competitiveness, *Going Global: The New Shape of American Innovation* (Washington, DC, September 1998); Progressive Policy Institute, *The New Economy Index: Understanding America's Economic Transformation* (Washington, DC, November 1998); Committee for Economic Development, *Basic Research: Prosperity through Discovery* (New York, NY: CED, 1998); Lester Thurow, "Building Wealth," *The Atlantic Monthly*, June 1999, pp. 57-69; and President Clinton's Remarks on Science and Technology Investments, California Institute of Technology, Pasadena, CA, Jan. 21, 2000.

[4] National Science Board, *Science Indicators—The 1985 Report* (NSB 85-1), ch. 8.

[5] National Science Board, *Science and Engineering Indicators—2000* (Arlington, VA: National Science Foundation, 2000, NSB 00-1), Appendix Table 6-32. Hereafter, this source is abbreviated as *Indicators—2000*.

[6] *Indicators—2000*, ch. 3.

[7] College graduates and citizens attentive to science and technology policy hold the most positive views. Chapter 8 of *Indicators—2000*, "Science and Technology: Public Attitudes and Public Understanding," elaborates on these themes.

[8] For example, see NSF GPRA *Strategic Plan, FY 2000-2005*, February 2000 Draft, NSB 00-16.

[9] National Science Board, *Toward the Next Century: The State of U.S. Science and Engineering* (Arlington, VA: National Science Foundation, February 1994, NSB 94-24), p. 4.

[10] Joel Achenbach, "Ingenuity," *Washington Post*, Dec. 31, 1999, p. M12.

[11] "Pathways of Discovery," *Science*, vol. 287, Jan. 14, 2000, p. 231. In the view of some, "DNA is likely to be the discovery made in the 20th century that will be the most important to the 21st." See Walter Isaacson, "Who Mattered and Why: The Century of Science and Technology, *Time*, Dec. 31, 1999, p. 54.

[12] Even before the cloning of "Dolly," questions were raised about who will own the map of the human genome, what are the limits to privacy in gene therapy, and what is the safety-profitability tradeoff in genetically-modified foods. All illustrate the "slippery slope" that policy must confront. For example, an executive order now prohibits Federal agencies from using genetic testing in any employment decision. Remarks by the President on Genetic Discrimination, American Association for the Advancement of Science, Washington. D.C., February 8, 2000.

[13] Dita Smith, "The Millennium Baby," *Washington Post*, Jan. 1, 2000, pp. A10-A11.

[14] Isaacson, op.cit., note 11, p. 57, notes that "Just as the flow of ideas wrought by Gutenberg led to the rise of individual rights, so too did the unfetterable flow of ideas wrought by telephones, faxes, television and the Internet serve as the surest foe of totalitarianism in this century." But concern continues to grow in the U.S. over the "digital divide" – the gap between those who have access, at home and in school, to IT hardware and software and those who do not. Chapters 8 and 9 of *Indicators—2000* explore evidence of this gap.

[15] See NSB Statement on the Sharing of Research Data, NSB 99-24, Feb. 18, 1999.

[16] Floyd E. Bloom, "The Endless Pathways of Discovery," *Science*, vol. 287, Jan. 14, 2000, p. 229.

[17] The following discussion is indebted to Chapter 1 of *Indicators—2000*, "Science and Technology in Times of Transition: The 1940s and 1990s."

[18] John R. Steelman, *Science and Public Policy*, vol. I (New York: Arno Press, reprinted from 1947), pp. 13, 26.

[19] William J. Clinton and Albert Gore, *Science in the National Interest*, Executive Office of the President, August 1993, p. 7.

[20] Committee on Science, U.S. House of Representatives, *Unlocking Our Future: Toward a New National Science Policy*, 105th Congress, Committee Print 105-B, September 1998, p. 12.

[21] These and related human resource issues are discussed in the Board's report, *Preparing Our Children: Math and Science Education in the National Interest*, NSB 99-31, March 1999.

[22] An NSB Symposium on International Models for S&T Budget Coordination and Priority Setting, in November 1999, examined decision making models in industrialized, centralized, and developing nations. Also see Committee on Science, Engineering, and Public Policy, *Capitalizing on Investments in Science and Technology* (Washington, DC: National Academy Press, 1999); and Lewis M. Branscomb and James H. Keller, eds., *Investing in Innovation: Creating a Research and Innovation Policy That Works* (Cambridge, MA: MIT Press, 1998).

[23] National Science Board, National Science Foundation, *Science at the Bicentennial: A Report from the Research Community* (Washington, DC: U.S. GPO, Apr. 30, 1976), ch. 1. The Board is currently grappling with methodologies for coordination and priority-setting in the Federal science and engineering research budget. See Charge to the Ad Hoc Committee on Strategic Science and Engineering Policy Issues, Mar. 23, 1999, NSB 99-56.

[24] Philip M. Smith, "Life Sciences' Stewardship of Science," *Science*, vol. 286, Dec. 24, 1999, p. 2448.

[25] In the view of *Business Week's* economics editor, "In the 1990s, at least, it seems that technology is more powerful than either taxes or deficits. No one is saying that the three are mutually exclusive. Lower interest rates from increased savings can encourage innovation. So can lower tax rates." Michael J. Mandel, "How Most Economists Missed the Boat," *Business Week*, Nov. 15, 1999, pp. 106.

[26] Note that the U.S. investment, which includes both military and civilian expenditures, is second in percentage terms only to Japan (whose R&D investment is all civilian). For national funding data, see the AAAS R&D Budget and Policy Program website <www.aaas.org/spp/dspp/rd/rdwwwpg.htm>.

[27] Congress has extended the Research and Experimentation tax credit for an unprecedented five-year period. See President Clinton Highlights Progress toward Building a High-Tech, High-Wage Economy, White House Press Release, Dec. 3, 1999. But the President's Information Technology Advisory Committee (PITAC), *Interim Report to the President* (Arlington, VA: National Coordination Office for Computing, Information, and Communications, August 1998), has warned that the Federal investment in IT is inadequate and "threatens to interrupt the flow of ideas that has driven the information economy in this decade" (p. 3).

[28] Also see National Research Council, *Measuring the Science and Engineering Enterprise* (Washington, DC: National Academy Press, 2000).

[29] *Indicators—2000*, Appendix Table 6-60. If coauthors from different countries are considered, the U.S. proportion grows 9.8 percent, Japan 7.1 percent, and the UK 12.6 percent.

[30] *Indicators—2000*, Appendix Tables 6-56 and 6-63.

[31] *Indicators—2000*, Appendix Table 6-65. However, articles resulting from "public research" – that performed in academic, nonprofit, and government research organizations, and funded primarily by Federal sources – are increasingly cited in U.S. patent applications. See National Science Board Working Paper, *Industry Trends in Research Support and Links to Public Research* (Arlington, VA: NSF, 1998, NSB 98-99).

[32] *Indicators—2000*, pp. 6-84 to 6-87 and Appendix Table 6-67.

[33] Of course, the Nobel Prize is given for only a subset of scientific fields. Omissions include fields such as information science and technology that did not exist at the time when the Nobel was established. For all fields in which the Nobel Prize is awarded, U.S.-based scientists represent two-thirds of the laureates, ranging from 54 percent in Chemistry to 77 percent in Economics. These tabulations are derived from the "Nationality or Citizenship Index" in Bernard S. Schlessinger and June H. Schlessinger, eds., *The Who's Who of Nobel Prize Winners* 1901-1995 (Oryz Press, 1996), pp. 243-244.

[34] *Indicators—2000*, Appendix Table 1-1. The prize was adopted as the unit of analysis, with multiple winners increasing the likelihood that at least one will have had NSF support. Laureates from foreign countries, of course, would be less likely to apply for U.S. funds.

[35] Remarks by President Clinton at the National Medal of Science Award Ceremony, Mar. 14, 2000.

[36] See President Clinton Fact Sheet on National Nanotechnology Initiative, Jan. 21, 2000.

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