National Science Foundation and National Institute of Standards and Technology Roles and Influences on STI Policymaking

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POLICY BRIEF

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National Science Foundation and National Institute of Standards and Technology Roles and Influences on STI Policymaking

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The purpose of this research brief is to describe the roles and influences on science, technology, and innovation (STI) policy decisions of the National Science Foundation (NSF) and the National Institute of Standards and Technology (NIST) in the United States. This paper focuses mainly on three key areas: the portfolio of expenditure on STI activities in the United States; the program portfolios at NSF and NIST; and the challenges decision-makers face as they attempt to optimize portfolio decisions.

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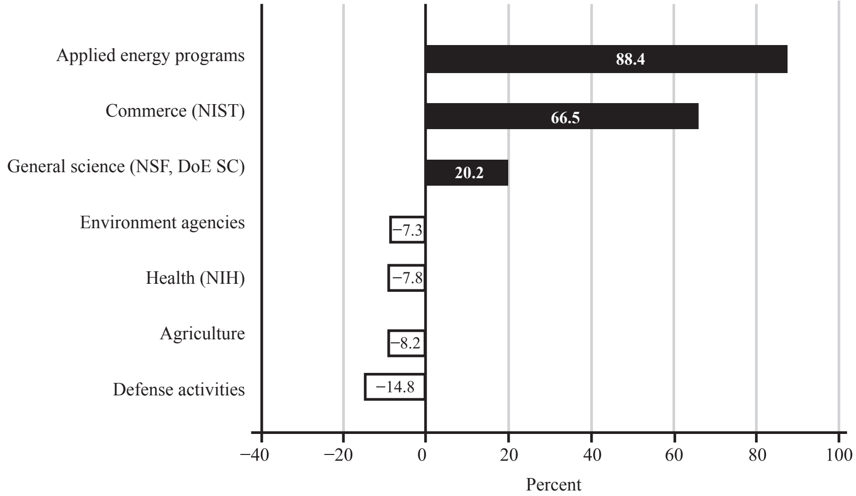
U.S. R&D EXPENDITURES

It is first important to give a brief description of the landscape of expenditures on research and development (R&D) in the United States. Although the private sector typically has the largest share of national expenditures on R&D in developed countries, public sector expenditures are considerable, ranging from around 25 percent to almost 80 percent for Organization for Economic Cooperation and Development (OECD) member nations. In 2009, the share of R&D expenditures by the U.S. federal government was approximately 31 percent, while that of private industry was almost 62 percent.[1] Just less than three percent of total output (gross domestic product or GDP) in the United States is spent on R&D by private sector firms and government agencies. In 2009, federal expenditure on R&D was $133 billion, and for fiscal year (FY) 2014, the budget request of the President of the United States for R&D is $144 billion. About half of that expenditure is designated for basic and applied research, and the other half goes to development activities.[2]

The Obama administration has laid out five major R&D priorities: innovation, clean energy, STEM education, infrastructure, and the environment. Billions more dollars are appropriated to fund S&T at the state and local levels, as well as on education outlays, some of which support the development of STEM talent.

For FY 2014, NSF is expected to be 4.3 percent of federal R&D expenditure.[3] Since 2004, R&D expenditure in the general sciences (funded by NSF and the Department of Energy) has grown about 20 percent, while R&D related to commercial applications (primarily funded by NIST) has grown 66.5 percent. The largest area of growth in R&D funding has been applied energy programs at 88.4 percent. In contrast, environmental, health (National Institutes of Health), agriculture, and defense activities have all seen retrenchment in R&D funding of between 7.3 and 14.8 percent (see Figure 1).



Source: Matt Hourihan, "Federal R&D in the FY 2014 Budget: An Introduction," in *AAAS Report 38: Research and Development FY 2014*, 14.

Figure 1. Changes in federal spending on R&D in the United States, FY 2004–2014

Around the globe, total R&D spending from the business, government and higher education sectors and from private non-profit institutions was $1.3 trillion in 2009, and reached $1.4 trillion by the end of 2012. That year, the United States, European nations, and Asian countries together comprised approximately 92 percent of global spending on R&D. Countries such as China, Brazil, Russia, Hungary, Malawi, Uganda, and South Africa are increasing their focus on R&D-intensive sectors, reportedly spending more than 1 percent of GDP on R&D.[4]

Arguably, these expenditures advance science and technological innovation, which in turn have deliberate and unintended impacts on other sectors, and on social well-being. With so much at stake, it is important to understand the principles and practices underlying decision-making at the agency and program levels. Critical questions include: 1) Where should federal R&D dollars be put—into various fields, technologies, regions, intramural, or extramural? 2) What would constitute a "balance" between biological and physical sciences? 3) Can research funds be spent in a way that refreshes the research enterprise sustainably? Although there is no formulaic representation that can be used to answer these questions, having better data and other analytical resources should improve decision-maker's ability to make adept choices in changing technological and budgetary environments.

The America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act (America COMPETES Act) was first enacted in 2007 and reauthorized in 2010. Reauthorization is pending in 2013. Its goal was to increase investment in innovation through increased expenditure on innovation-related activities at NSF, NIST, and the Departments of Education, and Energy. Innovation activities include R&D and STEM (science, technology, engineering, and mathematics) education. Funding was therefore targeted at the physical and engineering research and STEM education efforts. The act called for a doubling of budgets for targeted agencies for the ten-year period following its enactment. This ramp-up of funding is not expected to be realized within the original time frame. In fact, the gap between authorization and funding for programs at NSF has been increasing (a differential of 6.9 percent in 2011, 9.8 percent in 2012 and 12.8 percent in 2013). For NIST, the funding shortfall relative to authorization was 18.4 percent, 22.7 percent and 22.4 percent, respectively. The core areas of Research and Related Activities at NSF, and Scientific and Technical Research and Services at NIST, were not as severely curtailed as other programs at either agency.[5]

All of these facts and figures give an indication of "what is" but not "what should be." With all of these changes to the STI portfolio in the United States (and other countries for that matter), there is little analysis of why the funding is what it is, what effect a marginal change would have on outcomes, or how the practice of science could be affected over time, in different geographic regions, or in different disciplines. As a result, there is little understanding of how scientific communities respond to changes in funding within and across disciplines and countries, or to changes in program focus.

The Science of Science Policy Interagency Task Group published a road map to science policy decision-making, in part informed by academic literature and a survey of federal agencies regarding their practices (see Table 1). The findings are stunning, particularly since large amounts of funds are spent annually by these agencies and there are significant opportunity costs of misallocation of resources. The major findings are:

- The study of technology adoption and diffusion is largely confined to academia. Stronger links are needed between academic and practitioner communities.
- Although each agency has its own community of practice, the collection and analysis of data about the scientists and the communities supported by those Federal agencies is heterogeneous and unsystematic.
- Agencies use very different approaches and tools to develop scenarios that anticipate the effects of discovery and innovation.
- Approaches that are used by Federal agencies to determine program effectiveness span the spectrum from mature to those in the pilot stage, but there are many open research questions.
- Many critical questions about the quality and global nature of the STEM workforce, and about the impact of STI outcomes cannot be answered due to a lack of data.
- While the models and tools exist to examine the effectiveness of different approaches, there are gaps in the analytical structure, the data infrastructure, and how information is conveyed to policymakers.[6]

Models and tools	
Quantitative analysis	*Deterministic models:* Econometric, risk modeling, cost benefit, cost effectiveness *Stochastic models:* Agent based, system dynamics
Qualitative analysis	Case studies, peer/expert review, Delphi, strategic/logic
Visualization tools	Network analysis, visual analytics, science mapping, scientometrics
Data collection tools	Survey, web scraping, administrative data, data mining
Metrics	
Outcome	*Scientific/micro level:* Innovation, competitiveness, knowledge increase *Program/portfolio:* Effectiveness, value *Systems level:* Productivity, quality of life, workforce characteristics, GDP
Budget and performance	Earned value, process metrics, efficiency, marginal cost
Inputs	*Bibliometrics:* Citations, patents, scientific papers *Community/network:* Network value, effectiveness, structure, workforce

Source: Office of Science and Technology Policy, "The Science of Science Policy: A Federal Research Roadmap," November 2008, 25.

Table 1. Models, tools, and metrics used by federal agencies

The "science of science policy" is developing, with measured strides toward the development of methods for making better prospective evidence-based decisions, compared to the choosing existing-level-plus (or, these days, existing-level-minus) funding levels. The goal is "to build consensus on how best to develop analytical frameworks, decision-making tools, and data infrastructure that are rigorous, systematic, institutionally appropriate, and useful."[7] The biggest challenge appears to be the development of an analytical data infrastructure for the following reasons:

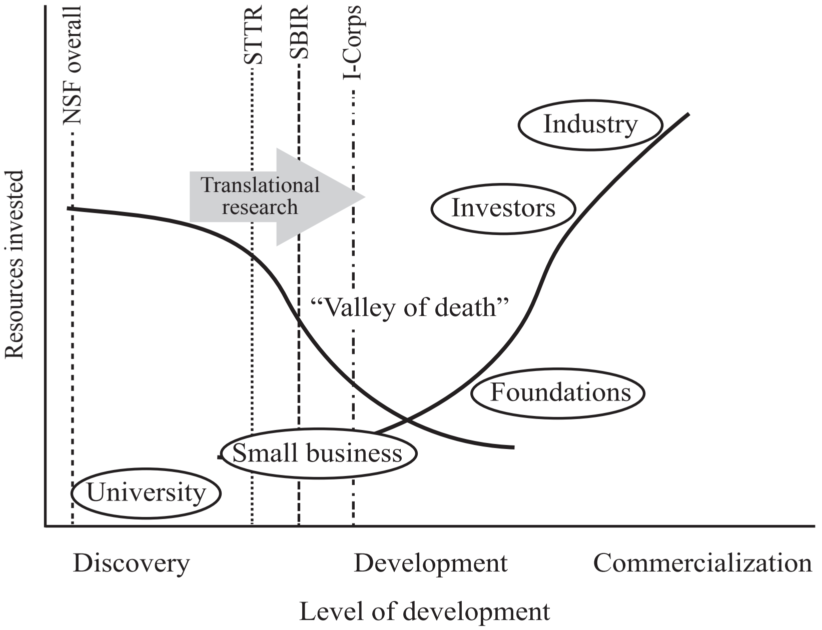
- Methodologies are complex and require conceptual understanding of theoretical underpinnings, rationales, goals, and implementation strategies for evaluation tools (including data taxonomies).
- There are concerns that the "evaluation methods du jour" will disregard the inevitable time lag for research to lead to scientific breakthroughs.
- Laborious and meaningless reporting requirements burden researchers and participants.
- New evaluation methods may be misunderstood or misused, leading to bad decisions.

NSF AND NIST PROGRAM DECISIONS

The National Science Foundation

NSF's mission was established by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense ..." The annual budget for FY 2013 is more than $7 billion, with the budget request of $7.6 billion for FY 2014. NSF is a bottom-up organization, funding frontier science and engineering identified through a peer review process. It is estimated that 20 percent of federally-funded basic research at U.S. colleges and universities is supported by NSF. In addition to R&D, NSF also funds STEM education, supporting K–16 education activities, as well as the training of postdoctoral fellows in some disciplines. Lastly, roughly 2.5 percent of NSF's budget is spent on major research equipment and facilities construction. This includes funding for the Advanced Technology Solar Telescope, Atacama Large Millimeter Array, National Ecological Observatory Network, Ocean Observatories Initiative, South Pole Station Modernization, and other large-scale infrastructure projects. This infrastructure is an important component of NSF's contribution to breakthroughs in frontier science.[8]

While NSF has been true to its core mission of funding discovery science, over the years the strategic plan has adapted to the changing academic, technological, and economic environments. The current strategic plan is built around three themes for NSF's science and engineering portfolio: empowering discovery and innovation; preparing today's students for tomorrow's challenges and opportunities; and improving NSF's effectiveness and efficiency. Empowering innovation is accomplished through NSF's support for basic and applied research. NSF also has programs that target the synapse between basic research and commercialization of new products and processes—bridging the "valley of death" (see Figure 2).



Source: Adapted from K. Olsen and A. Carlson, A. "Innovation in Science & Technology: What's Needed for Success?" National Science Foundation presentation, 2009.

Figure 2. The "valley of death"

NSF's Innovation Corps (I-Corp), the Robotics and Health program, and small business innovation research/small business technology transfer (SBIR/STTR) programs are funding leading-edge innovation activities that are closer to the development and commercialization end of the spectrum than discovery, although discovery science is likely to be activated in the process. The I-Corps program is described on its website as follows:

> The NSF Innovation Corps (I-Corps) is a set of activities and programs that prepare scientists and engineers to extend their focus beyond the laboratory and broadens the impact of select, NSF-funded, basic-research projects.
>
> While knowledge gained from NSF-supported basic research frequently advances a particular field of science or engineering, some results also show immediate potential for broader applicability and impact in the commercial world. Such results may be translated through I-Corps into technologies with near-term benefits for the economy and society.
>
> Combining experience and guidance from established entrepreneurs with a targeted curriculum, I-Corps is a public-private partnership program that teaches grantees to identify valuable product opportunities that can emerge from academic research, and offers entrepreneurship training to student participants.[9]

Although the SBIR/STTR program is not uniquely NSF's, the agency does fund roughly $120 million in grants in 48 states. Phase 1 grants are for a six-month period, and awards are $150,000. In Phase II, awardees are in the implementation phase of their projects, and received approximately $750,000 for two years. The award recipients may also apply for supplemental grants, totaling $500,000.[10]

NSF's applied programs and its core research programs rely on NSF's process: peer review; collaboration with other agencies on developing evidence-based STI policies; and curating bedrock data and metrics on STI activities in the United States, abroad, and in local regions. Reviewers are expected to have the following characteristics:

1. Special knowledge of the science and engineering subfields involved in the proposals to be reviewed to evaluate competence, intellectual merit, and utility of the proposed activity. Within reasonable limits, reviewers' fields of specialty should be complementary within a reviewer group.
2. Broader or more generalized knowledge of the science and engineering subfields involved in the proposals to be reviewed to evaluate the broader impacts of the proposed activity. Reviewers with broad expertise are required for proposals involving substantial size or complexity, broad disciplinary or multidisciplinary content, or significant national or international implications.
3. Broad knowledge of the infrastructure of the science and engineering enterprise, and its educational activities, to evaluate contributions to societal goals, scientific and engineering personnel, and distribution of resources to organizations and geographical areas.
4. To the extent possible, diverse representation within the review group. The goal is to achieve a balance among various characteristics. Important factors to consider include: type of organization represented, reviewer diversity, age distribution and geographic balance. [11]

The peer review process goes through periodic review to determine whether it is allowing efficient processing of proposals and allowing the best science to be funded. In FY 2011 the National Science Board augmented the two evaluation criteria that are central to NSF's review process: intellectual merit and broader impact. The current descriptions of those criteria are shown in Table 2.[12]

During FY 2011, NSF also established an internal committee to review its internal proposal evaluation processes. That committee had an external advisory committee of 12 scholars. The internal committee spoke to program directors at NSF and other agencies, researchers, and administrators, and piloted a few process options within selected programs at NSF. In addition to maintaining traditional NSF site panels and ad-hoc reviews, the committee considered other review processes that could reduce backlogs and burden on staff, while maintaining or even improving the quality of awards. These alternatives included: virtual panels; asynchronous reviewer discussions; screening proposals by streamline review; and preliminary proposals.

It should be noted that NSF review panels are instructed carefully to evaluate proposals based on the intellectual merit and broader impacts criteria. A highly-esteemed scholar cannot submit a proposal that does not meet these criteria with the expectation that funding is forthcoming. There are scores of cases where established researchers are not granted funding, while a young scholar with highly-ranked proposal will be funded. The foundation is also interested in "transformative" research, that is, high-risk, potentially high-reward research. Lastly, it is important to note that "broader impacts" of the research are evaluated during review. It is not enough for a proposal to appear to yield many published articles in highly regarded journals, but not have clear exposition in the proposal that the research will either have societal benefits, including the training of young researchers or researchers who are underrepresented in STEM fields.

Despite this rigorous peer review process, there are several challenges that NSF faces in this regard. It needs to integrate up-to-date techniques that allow the use of business-practice data (administrative records and unstructured data) to address big issues that require evidence and strategic thinking. Also, developing of a cross-agency taxonomy on science would allow better linkages across data collected at those agencies. Lastly, NSF needs to integrate data resources—including administrative records at colleges, universities, and funding agencies/organizations—to get more timely data on funding-research-outputs-outcomes-impacts (some say bench-bedside-community). This is where the work needs to be done.

Table 2. National Science Board evaluation criteria

Intellectual merit	**Broader impacts**
Important for advancing knowledge and understanding within own field and across different fields	Promotes teaching, training, and learning
Qualifications of proposer(s), including previous work	Broaden participation of underrepresented groups
Transformative concepts—creative, original	Enhance the infrastructure for research and education
Conceptualization and organization of proposed activity	Dissemination strategy
Sufficient access to resources	Benefits to society

Source: National Science Foundation, Proposal and Award Policies and Procedures Guide. Part I, III.A. http://www.nsf.gov/pubs/policydocs/pappguide/nsf13001/index.jsp.

The National Institute of Standards and Technology

With a targeted focus on measurement and technological innovation, NIST is included in the U.S. R&D budget. NIST's mission is "to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life." Specifically, NIST funds scientific and technical research and services, construction of research facilities, and industrial technology services. It is important to note here the service component of NIST's activities.

Measurement science and standards is the hallmark of NIST's projects. However, there are other key areas where NIST contributes to scientific breakthroughs and innovation. Advances in technological innovations such as lasers, global positioning systems, and wireless technologies rest on the research expertise that is supported by NIST. In addition, NIST's non-regulatory status enables it to perform an important role as a convener that facilitates collaboration between industry and government. Most recently, NIST has been focusing its budget in three key areas: cybersecurity (improved response to cyberthreats); nanomanufacturing (new measurement tools for advanced materials manufacturing); and energy (measurement and standards for energy security). NIST also has an SBIR/STTR program. For the fiscal year 2013, NIST allocated $2.3 million to 13 U.S. small businesses in this program. Phase I firms get roughly $90,000 each, while Phase II firms get up to $300,000 each. The companies are distributed across several states, and they are focusing on cybersecurity and manufacturing technologies.[13]

NIST has targeted some areas for improvements related to portfolio decision-making. The peer review system, though useful for expert advice on ranking projects for funding, presents a challenge given the evolution of new fields and the rise of interdisciplinary research. Program directors also feel that data for making good decisions on what to fund is lacking and that limited interoperability of databases within the agency presents a bottleneck in the funding process. There is also a need to get beyond just patents and licenses to show impacts, an issue that NIST does not face alone. Relatedly, it would be helpful to use streaming data coming off experiments to make funding decisions and to explain benefits of expenditures to general public. Despite these challenges, however, NIST is contributing to leading-edge technological capabilities in the United States, through its core measurement and standards mission, and through its support for technology transfer and commercialization of new products and process.

OVERARCHING CHALLENGES

In summary, NSF and NIST are dynamic contributors to the S&T capabilities of the United States. It is also important to recognize that NSF and NIST support of research, development, commercialization, and diffusion of technologies in the United States has spillover effects in other nations whose organizations are networked with domestic institutions funded by the two agencies. NSF and NIST have subnational impacts as well, particularly through its SBIR/STTR programs.

It is important to note, however, that there are still many challenges faced by these and other agencies in their respective roles in the STI ecological system. In a 2008 speech to the American Association for the Advancement of Science, John Holdren, who is currently the science advisor the President Obama, articulated five challenges that S&T policy can inform:[14]

1. Meeting the basic needs of the poor
2. Managing competition for the land, water, and terrestrial biota of the planet
3. Maintaining the integrity of the oceans
4. Mastering the energy-economy-environment dilemma
5. Moving toward a nuclear weapon–free world

These are worthy goals for any society to strive to attain, and science and technological innovation can be a positive catalyst toward achieving those goals.

Meeting the basic needs of the poor through technological innovation could have positive spillover effect to the whole society. "Inclusive innovation" is defined by the Global Research Alliance as: "the knowledge creation, acquisition, absorption and distribution efforts targeted directly at meeting the needs of the low-income or the base-of-the-pyramid (BoP) population. The focus of *Inclusive Innovation* is on delivering high performance products and services or high experience at ultra-low cost to the people whose needs are generally not addressed."[15] Therefore, both economic and social outcomes—social well-being—could be improved compared to the status quo. In addition, the public good aspect of funding basic research and some types of innovation activities (for example, education, which has both private and public good qualities) implies that agencies could observe broader impacts from their funding decisions, given the availability of appropriate data and other information.

Endnotes

1. Although the private sector had much higher expenditures on R&D, the federal government spent more than industry on basic and applied research. It should also be noted that private industry does a large share of the work accounted for as federal expenditures on R&D. For example, "[T]he majority of DoD's R&D portfolio is performed by private industrial weapons developers, while DoE's R&D portfolio is significantly dedicated to its national laboratories, and the NIH and NSF portfolios primarily fund research

at colleges and universities." M. Hourihan, "The Federal R&D Budget: Process and Perspectives," presentation for the Washington Internship for Students of Engineering (WISE) program, June 18, 2013, 16.

2. Intersociety Working Group, *AAAS Report 38, Research and Development FY 2014,* http://www.aaas.org/spp/rd/rdreport2014/.
3. American Association for the Advancement of Science, "R&D in the FY 2014 Budget by Agency," table, June 26, 2013, http://www.aaas.org/spp/rd/fy2014/total14p.pdf. Note that there is a difference between appropriations and performance data. Therefore, later in this paper NSF's funding level is given by NSF as $7 billion.
4. See New Partnership for Africa's Development, "African Innovation Outlook 2010"; Battelle Memorial Institute, "Global R&D Funding Forecast 2012," *R&D Magazine*, December 2012; OECD, "OECD Science, Technology and Industry Scoreboard 2011," September 20, 2011, doi 10.1787/sti_scoreboard-2011-en; National Science Board, "Science and Engineering Indicators, 2012." For African nations, the government and higher education sectors (where the education sector is heavily subsidized by government) are the biggest contributors to R&D activities, Ghana being the exception. Foreign sources of funds are also major contributors for R&D spending in Africa.
5. Congressional Research Service, *America Competes 2010: FY2012 Funding and FY2008–FY2011 Funding Summary* (Washington, DC: CRS, 2011).
6. Office of Science and Technology Policy, "The Science of Science Policy: A Federal Research Roadmap," November 2008.
7. Ibid.
8. National Science Foundation, "FY 2014 Budget Request," presentation by Dr. Cora Marrett, acting director, April 10, 2013, http://www.nsf.gov/news/speeches/marrett/13/cm130410_fy14budget.jsp.
9. See http://www.nsf.gov/news/special_reports/i-corps/.
10. See http://www.nsf.gov/eng/iip/sbir/.
11. National Science Foundation, "Proposal and Award Policies and Procedures Guide," Part I, III.B Selection of Reviewers, http://www.nsf.gov/pubs/policydocs/pappguide/nsf13001/index.jsp.
12. National Science Foundation, "Proposal and Award Policies and Procedures Guide," Part I, III.A Merit Review Principles and Criteria, http://www.nsf.gov/pubs/policydocs/pappguide/nsf13001/index.jsp. See also http://www.nsf.gov/news/news_summ.jsp?cntn_id=122794.
13. National Institute of Standards and Technology, "FY 2013 Small Business Innovation Research Program: Solicitation," http://www.nist.gov/sbir.
14. John Holdren, "Science and Technology for Sustainable Well-Being," *Science,* January 25, 2008, 424–34.
15. Global Research Alliance, "Inclusive Innovation," http://www.theglobalresearchalliance.org/en/What-we-do/Inclusive-Innovation.aspx.

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