The Science of Science Policy: A Federal Research Roadmap

Report on the Science of Science Policy to the

Subcommittee on Social, Behavioral and Economic Sciences
Committee on Science
National Science and Technology Council
Office of Science and Technology Policy

November 2008

About The National Science And Technology Council

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An important objective of the NSTC is the establishment of the clear national goals for Federal service and technology investments in areas ranging from information technologies and health research to improving transportation systems and strengthening fundamental research. The Council prepares research and development strategies that are coordinated across the Federal agencies to form a comprehensive investments package aimed at accomplishing multiple national goals.

For more information visit http://www.ostp.gov/nstc/html/NSTC_Home.html/.

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For more information visit http://www.ostp.gov .

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EXECUTIVE OFFICE OF THE PRESIDENT
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
WASHINGTON, D.C. 20502

November 13, 2008

Dear Colleague,

I am pleased to forward this document, "The Science of Science Policy: A Federal Research Roadmap." It was developed in response to my challenge for a new "science of science policy" that will begin to address the need for better scientific theories and analytical tools for improving our understanding of the efficacy and impact of science and technology policy decisions. It was prepared by an Interagency Task Group (ITG) commissioned by the National Science and Technology Council's (NSTC) Subcommittee on Social, Behavioral and Economic Sciences (SBE).

This Roadmap represents the first organized description of the emergent field of the Science of Science Policy, outlining scientific theories and defining terms that encompass efforts in the field thus far. It highlights the potential for greatly increasing the knowledge base and providing needed insights to improve the data, tools and methods that would enable a more rigorous and quantitative basis for science and technology policy. The Roadmap identifies ten major science questions grouped into three broad themes: Understanding Science and Innovation; Investing in Science and Innovation; and Using the Science of Science Policy to Address National Priorities.

Agencies and departments across the Federal Government face similar challenges when setting scientific priorities and assessing the effectiveness of current and planned investments. By working together to address these themes and questions, share best practices and collaborate on fundamental principles, we will greatly enhance our ability to maximize our critical investments in science and technology.

Sincerely,

John H. Marburger, III
Director, Office of Science and Technology Policy

Contents

Executive Summary

What is the Science of Science Policy?

The science of science policy (SoSP) is an emerging field of interdisciplinary research, the goal of which is to provide a scientifically rigorous, quantitative basis from which policy makers and researchers can assess the impacts of the Nation's scientific and engineering enterprise, improve their understanding of its dynamics, and assess the likely outcomes. Research in SoSP could be utilized by the Federal Government, and the wider society in general, to make better R&D management decisions.

The term "science of science policy" was first used by Dr. John H. Marburger III, the President's Science Advisor and Director of the Office of Science and Technology Policy (OSTP) in his keynote address to the American Association for the Advancement of Science (AAAS) Science and Technology Policy Forum in April, 2005[1]. This was expanded in a May 2005 Science magazine editorial (see Appendix B). In that editorial, Dr. Marburger called for the creation of a community of practice that would create the data sets, tools, and methodologies needed to assist science policy decision makers as they invest in Federal research and development and make science policy decisions. A National Science and Technology Council (NSTC) Interagency Task Group (ITG) was created in 2006 to develop a coordinated Federal approach to the science of science policy to meet these challenges.

Primary Conclusion of the Interagency Working Group:

"Expert judgment" remains the best available decision support tool for science policy makers, but a nascent community of practice is emerging in the science policy arena that holds enormous potential to provide rigorous and quantitative decision support tools in the near future. Support and development of this emerging community of practice can provide the Federal government with these much-needed decision tools.

A National Imperative for a Science of Science Policy

Development of the science of science policy is critically important to our Nation's ability to benefit most effectively from R&D investments. In 2007, the U.S. Federal government R&D budget totaled $139 billion[1].

Although the importance of public investments in science, technology, and innovation is understood, the rationale for specific scientific investment decisions lacks a strong theoretical and empirical basis. Accordingly, given the magnitude of the Federal investment and the importance of that investment to our Nation, science policy decision makers must have at their disposal the most rigorous tools, methods and data that will enable them to develop sound and cost-effective investment strategies.

The ITG undertook a literature review to determine the state of the science to date. A questionnaire was also circulated to Federal agencies to ascertain what methods are currently in use for programmatic investment decision making, as well as to ask what tools and resources are needed by Federal agencies that are currently unavailable. The ITG found that:

- There is a well developed body of social science knowledge that could be readily applied to the study of science and innovation.
- Although many Federal agencies have their own communities of practice, the collection and analysis of data about the science and scientific communities they support is heterogeneous and unsystematic.
- Agencies are using very different models, data and tools to understand their investments in science and technology.
- The data infrastructure is inadequate for decision-making.

- New tools and data sets could be developed and used to quantify the impact that the scientific enterprise has had on innovation and competitiveness.

This Federal Research Roadmap identifies three broad theoretical themes, with 10 underlying scientific questions within those themes, and makes several recommendations on how to address those questions. More generally, the following next steps are recommended for overall implementation of the Roadmap.

Next Steps

- Federal government agencies should work in concert to establish a theoretical and empirical framework to understand the science and engineering enterprise within the context of the science of science policy. Tentatively described in this report as a "Federal Innovation Framework," analyses could be performed on how Federal investments and policy decisions affect the Nation's system of innovation.

- Establish interagency research priorities to address the scientific challenges confronting the unique science policy analysis needs of Federal science and technology agencies.

- Encourage investment in the development and use of emerging tools, methods, data, and data infrastructure to enable science policy decision makers to base investment decisions on more rigorous and quantitative analyses.

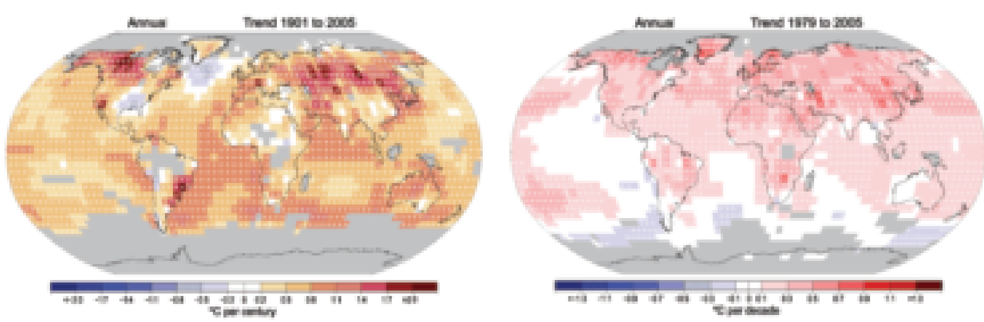
- Hold a public, international workshop to discuss the scientific basis of the Roadmap and its implementation in the policy arena. The workshop will serve to further inform the U.S. Federal approach to the science of science policy in a broader, international context.

Introduction

The National Imperative

Federal investments in science and technology have had an enormous impact on innovation, economic growth, and social health and well-being. In addition to furthering these impacts, future investments by the Federal government will be critical in many arenas, such as mitigating the consequences of global climate change, exploring new energy sources, defending against external threats, and maintaining international competitiveness. Given the importance of those investments, it is imperative that science policy decision makers have at their disposal the most rigorous tools, methods and data that will enable them to develop sound investment strategies.

And yet the science policy analysis community does not have the best tools, methods and data that would allow decision makers to make and manage such future investments optimally. As a result, science policy discussions are frequently dominated by advocates for individual scientific fields who argue for their particular interests, but leave policy makers with little ability to objectively discriminate between investment options. Policy decisions may be based upon past practices or data trends that may not always accurately reflect current conditions.
Across the Federal government, there is an urgent need for rigorous analysis that can inform Federal research



Climate change is one of the major science challenges that would benefit from science policy analysis and decision making.
Linear trend of annual temperatures, National Climactic Data Center.
National Oceanic and Atmospheric Administration,
http://www.ncdc.noaa.gov/oa/climate/globalwarming.html#q4.

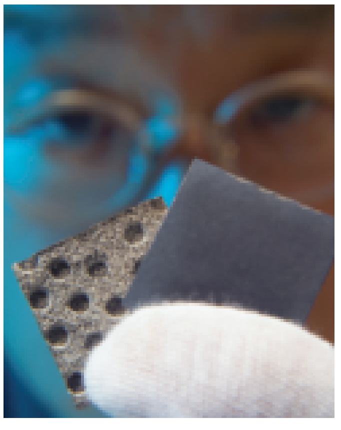
and development decision-making. Investments in many strategically important frontiers of science and engineering and the allocation of Federal resources across a complex and decentralized national research and development (R&D) portfolio must be guided by the best data and analysis available. A "science of science policy", first named by the President's Science Advisor, Dr. John Marburger, must be developed.

The importance of this challenge derives from the magnitude and centrality of the contribution that science and technology make to the U.S. economy. In 2007, the U.S. Federal government R&D budget totaled $139 billion2, affirming the importance of Federal investments in science and technology.3 It is imperative to advance the scientific basis of science policy so that limited Federal resources are invested wisely. Scientific models must be developed, along with methods of collecting real-time quantitative and qualitative data so that future policy decisions are based on sound science and informed by meaningful metrics. Retrospective analysis is also needed, to analyze the impact of Federal investments on scientific discovery and innovation, the economy, and society. In this way, past investments may help inform future decisions, refine the accuracy of models, and maintain the nation's dominance in the scientific arena. While federal decision-makers grapple with competing priorities to make the best decisions for their own agencies, the rest of the world is vastly increasing its scientific investments, and there is increased foreign competition for scientific ideas and talent. The United Kingdom has established a Department for Innovation, Universities and Skills; Saudi Arabia has invested $6 billion to establish a University of Science and Technology; and almost every developed European and Asian country is aggressively investing in and competing for scientific talent. Thus, science and technology policy and the choice of scientific investments remain at the forefront of the national debate.

Scope of the Science of Science Policy:

The science of science policy includes basic and applied research, as well as technology development, demonstration, and deployment. It includes operational science and technology, from early to later stages in operational life cycles. It is thus comprehensive of the entire spectrum of innovation in science and technology activities, from high-risk, undirected activities to low risk, applied activities.

The Scientific Challenge



TuffCell bi-polar plates
Argonne National Laboratory
http://www.anl.gov/

Developing a science of science policy will require the implementation of a rigorous and systematic research program that is focused on addressing a number of scientific and data challenges, ensuring that the needs of Federal R&D agencies and senior decision makers are met. Its creation as a scientific field of study requires the development of analytical tools, data bases, and management processes capable of providing reliable information and the best possible basis for the allocation of public funds available to support Federal R&D. It could be built upon the emerging community of science in this area, and existing expertise in policy analysis that is resident in the Federal science agencies and elsewhere in the Federal government. A community of practice in academia and in the private sector could also be developed that would provide support to Federal policy makers.

Current science and technology investment decisions are based on analyses that lack a strong theoretical and empirical basis. Increasingly, economic value is based on generating and selling ideas, rather than physical goods and agricultural products, but the current social scientific and statistical infrastructure has not kept pace with this change in the nature of economic activity. Indeed, while it is a common belief that innovation is closely related to investments in science and technology, there is actually a limited theoretical and scientific foundation underlying such beliefs.

But there is an emerging view that many facets of the U.S. innovation ecosystem have become too complex for expert judgment alone to be an effective decision support tool. Science continues to accelerate, and multidisciplinary collaborations are becoming more common; as a result, the complexity of the scientific endeavor is surpassing the ability of experts within particular scientific disciplines to understand its totality. The tenuous nature of the scientific links between investments in science and desired outcomes is evident from the variety of ways in which outcomes are characterized: sometimes by the entity funding or conducting R&D (e.g., universities, governments, or businesses), sometimes by the phase of discovery (e.g., basic research, applied research, or development), and sometimes in terms of the end products (e.g., products, processes, organizations, or knowledge).

This complexity creates a number of challenges for science policy, and is the subject of a vigorous scientific debate. These challenges include determining the appropriate roles of various Federal agencies in different disciplines, addressing a host of agency policy and investment questions about the appropriateness of disciplinary or institutional portfolios, and understanding the relative value added of different fiscal policy stimuli. In order to address this need, the Office of Management and Budget and the Office of Science and Technology Policy have encouraged Federal science and technology agencies to work cooperatively to bring the emerging science of science policy community of practice into a mature state, via the annual "Administration Research and Development Budget Priorities" memoranda. [4,5]

Graduate student
Lawrence Berkeley National Laboratory
http://www.lbl.gov/.

The Interagency Task Group (ITG) Charge and Findings

In recognition of the importance of developing a science of science policy, NSTC established the Science of Science Policy ITG, under the purview of the Subcommittee on Social, Behavioral, and Economic Sciences (SBE). The Co-Chairs of the ITG are representatives of the U.S. Department of Energy (DOE) and the National Science Foundation (NSF). Other participating agencies include the Departments of Agriculture (USDA), Commerce (DOC), Defense (DOD), Education (DOEd), Health and Human Services (DHHS), Homeland Security (DHS), Interior (DOI), State, Transportation (DOT), and Veterans Affairs (VA), as well as the National Aeronautics & Space Administration (NASA), the National Institutes of Health (NIH), the US Geological Survey (USGS), the Centers for Disease Control and Prevention (CDC), the National Institute of Standards and Technology (NIST), the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), OSTP, and OMB. The Interagency Task Group had a number of charges as articulated in its Charter (see Appendix A).

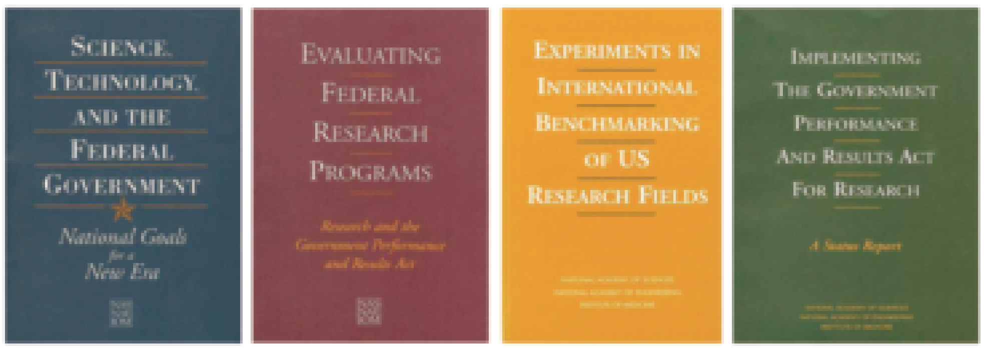
First, the ITG developed the following definition of the science of science policy:

> *"The science of science policy is an emerging interdisciplinary research area that seeks to develop theoretical and empirical models of the scientific enterprise. This scientific basis can be used to help government, and society in general, make better R&D management decisions by establishing a scientifically rigorous, quantitative basis from which policy makers and researchers may assess the impacts of the Nation's scientific and engineering enterprise, improve their understanding of its dynamics, and assess the likely outcomes. Examples of research in the science of science policy include models to understand the production of science, qualitative and quantitative methods to estimate the impact of science, and processes for choosing from alternative science portfolios."*

Next, the ITG completed four tasks to address its charge: 1) A review of current Federal efforts related to the science of science policy; 2) Examination of the data that are available for analysis; 3) Development of a literature synthesis that brings together academic research from many different disciplines; and 4) Development of a roadmap that would chart a path forward for the Federal government to build a community of practice as well as tools in the science of science policy. This work was assisted by groundwork laid by the new grant program in NSF's Directorate for Social, Behavioral, and Economic Sciences: the Science of Science and Innovation Policy (SciSIP). The program, although independent of the ITG, provided many insights, particularly with regard to the literature synthesis.

The first task, a review of current Federal agency efforts that could be viewed as supportive of the science of science policy, found the following:

- A number of Federal agencies have developed substantial capabilities for R&D program planning and evaluation to develop and manage their R&D portfolios, measure program progress toward strategic goals, and to address other operational and policy issues. The vast majority of those capabilities relies upon "expert judgment" and does not use quantitative models or decision analysis tools. This is consistent with findings from several reports done by NAS in the 1990s that identified expert judgment as the primary tool available to science policy makers.[6] The NAS went further in a 2008 report which stated that "the most effective mechanism for evaluating investment efficiency of R&D programs is an expert-review panel." [7] It may be noted that these reports are largely silent on evaluations across programs or the establishment of investment priorities among programs in different fields.



The NAS has published four reports since 1993 that examine how to assess the benefits and effectiveness of Federal investment in science and technology.

- Science and technology agencies expended considerable effort in response to the requirements for strategic planning and evaluation imposed by the 1993 Government Performance and Results Act (GPRA). This attention to management, planning, and evaluation was amplified in 2001, as science and technology programs increasingly became the subject of OMB's Program Assessment Rating Tool (PART) assessments. During this period, many agencies found creative ways to utilize expert judgment and other types of quantitative and qualitative decision analysis tools to meet GPRA and PART requirements.

The ITG next examined data needs and found the following:

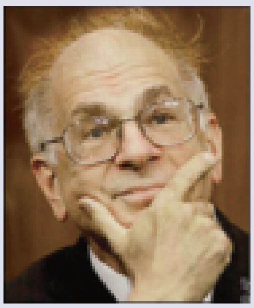
- The agencies responsible for collecting national science and economic statistics, such as NSF and DOC, are increasingly focused on better ways to gauge the effects of R&D investment on the production of new knowledge and technology, on innovation, and their ripple effects throughout the economy.
- Dr. Marburger addressed the Organization for Economic Cooperation and Development (OECD) regarding Science of Science Policy needs in July 2006.[8] Since that time, the statistical and analytic committees of the OECD - to which the United States has been a major contributor and participant – have devoted much effort to measuring the strength and

"Complexity economics is part of the larger area of complex adaptive systems that incorporates methods from the study of such systems in physics, biology, computer science, and other fields."

- Science of Science Policy: An Exploration of Literature and Practice, created on behalf of the Science of Science Policy ITG by the Science and Technology Policy Institute

effectiveness of the innovation infrastructures of member countries and their contributions to national economic growth.

- The research data infrastructure suited to examining science and innovation policy is insufficient to support today's requirements. Resources are wasted because researchers are often forced to use data that is not collected for research purposes or within the appropriate scientific context. As a result, their analytical work frequently cannot be generalized. Limited access to data often means that analytical work cannot be replicated.



Nobel Laureate Daniel Kahneman: The 2002 Nobel Prize was awarded to psychologist Daniel Kahneman for demonstrating that in situations with uncertainty, human judgment often exploits rules of thumb which systematically contradict fundamental propositions in probability theory.

An important finding in the science policy context is that individuals are much more sensitive to the way an outcome deviates from a reference level (often the status quo) than to the absolute outcome. When faced with a sequence of decisions under risk, individuals thus appear to base each decision on its gains and losses in isolation rather than on the consequences of a decision for their wealth as a whole.

2002 Nobel Prize Press Release

Finally, the ITG commissioned a literature synthesis designed to review academic research in science policy and related fields. This synthesis examined economic theory, social and behavioral sciences, the physical and biological sciences, and a host of other disciplines that could provide insights into analytical methods, tools, and data sets useful to the science policy community, such as the emerging theories of complexity in mathematics and systems biology. The ITG also reviewed other work, most notably a report by the NAS's Committee on Science, Engineering and Public Policy (COSEPUP)[9] and ongoing work by the OECD.[10] This synthesis led to the conclusion that systems level analysis from biology, complexity theory, social network analysis, industrial dynamics and other disparate fields have rich potential for the future of the science of science policy. A primary conclusion of the ITG is that practitioners from these related fields should begin working to mine that potential for SoSP.

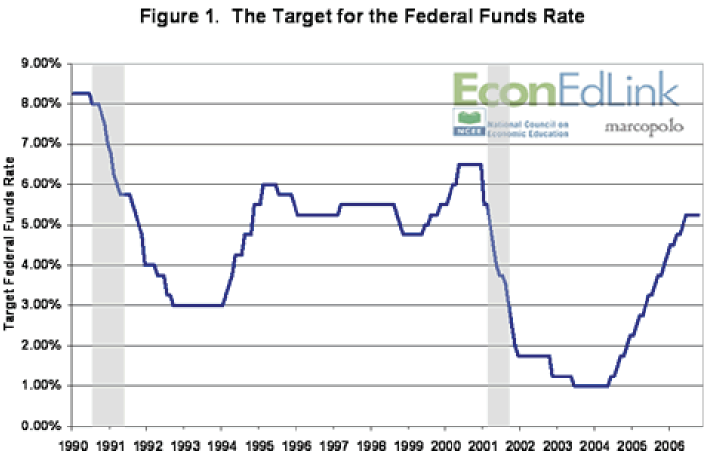
Based upon these three undertakings and their subsequent findings, the ITG formed the primary scientific themes and questions which comprise the current state of the Science of Science Policy. These were incorporated into the Roadmap, which sets forth a series of recommendations to advance the field of SoSP.

The Science of Science Policy Roadmap

The ITG identified three scientific themes and 10 major questions faced by scientific agencies if they are to help support the development of the SoSP community. They are listed under broad conceptual categories below; the associated recommendations are identified in the next section.

Theme 1: Understanding Science and Innovation

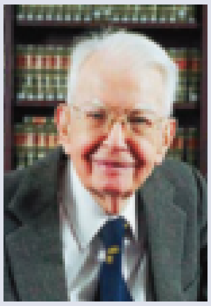
Establishing a scientific framework for understanding science and innovation is fundamental if policy makers are to understand the ways in which their decisions are likely to play out. Because innovation in scientific disciplines relies on human achievement, interaction and behavior, research should be grounded in the core social and behavioral science disciplines of economics, sociology, psychology, and political science. Theoretical models of innovation must be developed, in the same way that economists have developed theoretical models of economic activity. This will provide a context for data collection. Just as the Federal Reserve Board's econometric model is based on a strong theoretical foundation describing economic behavior, a theoretical model could be used to develop the empirical framework upon which to base investment decisions in science.



The Federal Reserve uses its econometric model to set monetary policy. http://www.econedlink.org/lessons/index.cfm?lesson=EM712&page=teacher

The following list identifies the key questions that must be addressed in order to develop such a scientific framework.

Question 1: What Are The Behavioral Foundations Of Innovation?



Nobel Laureate Ronald Coase: The 1991 Nobel Prize was awarded to economist Ronald Coase for finding that the institutional structure of the economy may be explained by the relative costs of different institutional arrangements, combined with the parties' efforts to keep total costs at a minimum.

Alongside price formation, the formation of the institutional structure is regarded as an integral step in the process of resource distribution.
1991 Nobel Prize Press Release

Innovation, the act of creating or inventing new ideas or methods, has a basis in social and behavioral activity. The examination of the foundations of our social and economic systems by social scientists has led to a deeper understanding of economic, social, and cognitive principles, resulting in a number of Nobel prizes, yet there has been little focus on the social and behavioral foundations of innovation in science and technology. Initial findings may provide a basis for the development of more dynamic research programs in this area. For example, psychologists funded by NSF have developed models of cognitive processes across individuals and groups intended to promote innovation. Psychologists have also studied trans-disciplinary research teams. Examples of these include partnership teams between biomedical and nanotechnology industries, the collaboration between academic and non-academic scientists (in fields such as hydrology, soil and water science), and the development of virtual social networks (Internet based). Economists and sociologists have begun to extend models of the impact of different incentive and organizational structures on human behavior to the scientific enterprise. Some Federal agencies, such as NIH and DOE, have begun to use social network analysis techniques to understand the process of innovation.

Finding: The ITG's review of the literature suggests that while there is a well-developed understanding of human and social behavior in multiple disciplines such as economics, psychology, and sociology, this understanding has yet to be applied to the study of innovation within the scientific enterprise, leaving enormous gaps in scientific knowledge. For example: how does the discovery process work at the individual and team level? How could creative insights be stimulated? Which institutional structures facilitate the discovery to innovation cycle?

Question 2: What Explains Technology Development, Adoption And Diffusion?

Technology is the application of science, especially to commercial and industrial objectives. Of key interest, then, is advancing understanding of how technology is adopted, who adopts technology and how it spreads through society. The current plethora of theories and models that could inform Federal decision-makers in moving R&D to deployment, operations, and private sector applications, needs to be advanced and applied to the current context. This would help inform decisions as to whether funding increases, tax changes, regulatory changes, or other policy interventions are more or less likely to stimulate technology development, adoption and diffusion.

It is clear that technology adoption and diffusion is a complex process; there is not a linear succession from basic research to the market, via applied research, technical development, production and marketing. Businesses and government rely upon various decision-making tools that promote technology adoption – including considerations about the return on investment (ROI), intellectual property valuation, consumer preferences, and many other factors that enable technology adoption – but how those decision rules interact and lead from the maturation of a scientific concept into a market-based technology is currently unclear. It is also important to understand how leaders (those likely to take the greatest risk and adopt a technology early) behave within a specific social network. In some instances, less scientific considerations such as the reputation of the early adopter play a key role in whether a technology gains access and diffuses successfully.

There are indications that answers can be found. The role of economic incentives in technology adoption has been clear since Griliches's analysis of the adoption of hybrid corn in developing countries.[11] Human capital is also a critical element: researchers have found that technology diffuses through social networks, since these reduce learning costs, enhance usability and sustainability, and create a social incentive structure. Researchers at NIST, for example, have learned that collecting data on businesses and collaborating with academic researchers enables government to do the analyses that promote economic growth by encouraging the development of "disruptive innovations". Depending entirely on high-tech startups to develop disruptive innovations and introduce them to market—waiting for small technology firms to mature into, or merge with, larger firms, thereby transforming industries from the bottom up—is a strategy that is both slow and uncertain, but NIST has learned that technology adoption can be accelerated through certain targeted investments. Current research also suggests that large firms increasingly have a need for external partners to help them overcome internal, as well as external, barriers to the development of disruptive innovations.[12]

Finding: The investigation of technology adoption and diffusion has been largely confined to the academic realm. Some government agencies, such as NIST, have collected data in a scientific fashion, and have supported basic research. However, challenges remain, such as the development of technology adoption models, as well as research on full systems approaches to mapping science, technology, and innovation. This research could be significantly advanced by developing stronger links between the academic and practitioner communities.

DEFINITION: DISRUPTIVE INNOVATION:

The term "disruptive technology" was first described by Christensen as the creation of cheaper, simpler- to-use versions of existing products (in contrast to "sustaining technologies", which provide incremental improvements on existing products). Now the term "disruptive innovation" is commonly used to describe any technological innovation, product, or service that uses a "disruptive" strategy, rather than a "sustaining" strategy, to impact existing dominant technologies or status quo products in a market. Disruptive innovations may create entirely new markets, or new customers within existing markets.

Clayton Christensen, The Innovator's Dilemma (Harvard Business School Press), 1997.

Question 3: How And Why Do Communities Of Science And Innovation Form And Evolve?

Communities of science provide the backdrop for promoting scientific discovery and innovation. Building on the existing understanding of how such communities evolve would have clear implications for investment decisions. Research funding, for example, could be structured to encourage the formation of new communities, as is currently occurring through the large Federal investment in the nanoscience and synthetic biology communities. Studying the behavior and formation of communities could avoid unnecessary duplication, since a feature of communities is the joint study, documentation, and communication of scientific advances. Finally, using communities as the unit of analysis is another way of tracking the scientific impact of investments. It is apparent that the increasing complexity of science means that institutional and disciplinary boundaries are no longer the organizing principle for the development of communities. Social scientists have been able to use new tools to advance understanding of social network theory, although the data requirements are complex and evolving. The field of study of virtual organizations is also emerging, with a first solicitation by NSF's Office of Cyberinfrastructure.

A number of research agencies have developed the infrastructure to study communities. For example, USDA science agencies are using its Current Research Information System (CRIS) to keep track of performers.

SCIENCE POLICY IN ACTION: BIOTECHNOLOGY RISK ASSESSMENT RESEARCH

USDA is funding work on the multi-dimensional issues regarding the adoption and diffusion of biotechnology. These issues revolve around agriculture and food systems, markets and consumers, businesses, institutions, and social issues.

Ag Engineer and Corn, Agricultural Research Service, U.S. Department of Agriculture

The changing agriculture enterprise in the 21st Century includes increasing use of transgenic crops. While these crops have been widely adopted in the United States to great benefit, there remain a number of concerns about their adoption that have created barriers to their sale and export to a number of countries.

"Emerging economies learned a key lesson: investment in innovation capacity is the key to higher productivity, higher wages and higher economic growth. Emerging economies are investing in research and virtual, physical and educational infrastructure. Global companies are establishing additional innovation capabilities in the emerging world as they increasingly collocate R&D with new market opportunities. While the United States is the world's strongest innovator nation today, a wide range of surveys shows that many companies plan to establish high value and knowledge-intensive operations offshore, including R&D, and that emerging economies are now among the most attractive destinations for that investment.

Five for the Future. Council on Competitiveness, 2007.

Relational databases are being developed by academics, and NSF has funded the study of complex distributed project teams developed under individual solicitations, such as its Information Technology Research program. DOE has funded three separate social network studies targeted at the high-performance computing and nanoscience communities.

Finding: Although each Federal 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. There is little analysis of the way in which the practice of science has become distributed across space, time, and research areas as a result of computational advances. As a result, there is little understanding of how scientific communities respond to changes in funding within research areas and across national boundaries, or to changes in program foci. For example, how important are national and international human capital flows? What is the role of the Internet and cybertools in communicating scientific ideas within and across communities? How do different mixes of research performers (industry, Federal laboratories and universities) influence the development of science communities?

Theme 1 Recommendations

The ITG recommends that Federal government agencies work in concert to establish a theoretical and empirical framework to understand the science and engineering enterprise within the context of the Science of Science Policy.

- An NSTC Working Group should regularly perform portfolio analyses of the full spectrum of SoSP across the Federal government and provide the President's Science Advisor with their results. These analyses are tentatively described in this report as a "Federal Innovation Framework," which analyses how Federal investments and policy decisions affect the Nation's system of innovation.

- NSF and other agencies should continue to support the development of a theoretical foundation through existing programs of investigator-initiated research. Workshops and informational websites can facilitate that dialog.

"Policymakers must often decide whether to make a choice on a current assessment of the costs and benefits of taking action based on imperfect information or to await additional scientific and technical information. Moreover, while scientific knowledge and technological development is changing constantly, the same is not always true of public policy. As a result, policies developed a number of years ago may not reflect the latest scientific and technological knowledge."

Stine, D. D. Science and Technology Policymaking: A Primer. Congressional Research Service, April 2008.

- Individual agencies should work together to identify a core suite of ways to measure and describe technology adoption and diffusion. They should also develop ways in which the many scientific communities of practice for each agency could be described and analyzed. Working subgroups such as these would be responsible generating a report to the larger Working Group.

- Federal agencies could work with international counterparts to develop a consistent approach to the Science of Science Policy that transcends national boundaries, potentially through the OECD or international meeting symposia.

> **DEFINITION – FEDERAL INNOVATION FRAMEWORK:**
> Analyses of the scientific theories on science and technology policy decision making that explain how federal investments and policy decisions affect the nation's system of innovation, and provide an empirical framework to understand the Nation's science and engineering enterprise. It includes ongoing evaluation of the relevant tools and metrics utilized by different Federal Agencies. The Federal Innovation Framework group, led by OSTP, will include feedback loops that analyze the impact of various policy instruments. This will require cooperation with a wide variety of Federal agencies, including the Department of Treasury, DOC and the major Federal statistical agencies to understand the effects of tax policy, labor policy and other Federal efforts that impact science policy.

Theme 2: Investing in Science and Innovation

The pragmatic reality facing Federal agencies is that the resources available for investing in research are limited. Each agency, and each program within an agency, either explicitly or implicitly, makes decisions about the allocation of those resources on an ongoing basis. The ITG's review revealed that agencies use different methods and tools to make those allocation decisions. Federal agencies have developed budget support processes that enable them to make investment decisions on an intra-agency basis, but the increasing complexity of the science conducted by those agencies is becoming daunting. NIH, for example, must manage a budget process that supports 27 separate institutes, while the DOE manages a budget process that includes nine major R&D offices that invest in a varied and complex range of sciences and technology. The problem is compounded when determining the benefits of investments *across* agencies or national boundaries.

Question 4: What Is The Value Of The Nation's Public Investment In Science?

There is a wide body of scientific and technical knowledge created solely through Federal research and development investment, which would not typically be sought through private investment (i.e. generation of this knowledge does not have an immediate or obvious "payoff"). Value, in the Federal context context, is thus twofold, and refers to both the value of the knowledge produced by governmental efforts (how much is the knowledge worth?), as well as the value of developing that knowledge through governmental efforts (what is the value of learning this with public funds?). Frequently, these values are not known until viewed in historical or anecdotal context. In order to make more informed and prioritized research investments, Federal agencies have a need to better understand the value of the knowledge likely to be produced from their research investments in real time. Failure to do so has very real consequences. For example, the famous observation of Nobel Laureate Bob Solow: "You can see computers everywhere except in the productivity statistics", turned out to be due to a misinterpretation of data. This not only led to an understatement of U.S. economic growth, but also to a fundamental misunderstanding of the importance of information technology in contributing to growth.[13]

There are many methods of valuing publicly funded knowledge, but most of them rely solely upon qualitative assessments, such as committee reviews and case studies. Various agencies, however, have begun efforts to develop complementary quantitative methods designed to address the value question within their own context. For example, DOE has begun to develop risk assessment and modeling tools that could provide insights into the value of a mixed portfolio of energy efficiency investments.[14] Other efforts developed by agencies include measuring patents, citations, prototype products and processes, business finance measures, as well as collaborative relationships formed and publications.[15, 16] NIH counts the reductions in the direct and indirect costs of illness, as well as reductions in intangible costs due to increases in longevity in better quality of life. In addition, NSF's SciSIP program has funded researchers who are attempting to document the benefits from publicly funded international collaboration in bio-fuels, as well as the contributions of foreign graduate students and post-doctoral students to knowledge creation and diffusion.

Finding: Although determining the value of publicly funded knowledge is a critical outcome measure for Federal science agencies, the analysis is largely agency specific. Many of the tools are of uneven quality and the broader discourse is often anecdotal. Many open research questions remain. For example, is it possible to develop a full systems approach to mapping science, technology, and innovation? Is it possible to put in place a complete accounting of intangible assets and their contributions to science and technology outcomes to create an overall scientific measure of return on investment? How can the community develop more inclusive measures to capture the spillover effects between scientific discovery and technological innovation, particularly among universities, companies, and government laboratories?

The creation of a Federal Innovation Framework, as proposed here, could provide a forum within which varied community practices can be shared. This Framework group would stimulate dialog promoting a better understanding of which decision support tools could be used by different agencies, allow for joint data collection efforts, and stimulate more rigorous methods of analyzing the scientific process among different agencies.

Question 5: Is It Possible To "Predict Discovery"?

It is extremely unlikely that any single model could predict *particular* discoveries and any attempt to build such a model should be looked upon with great skepticism. New advances in agent based modeling and an increased capacity to simulate different scenarios, however, hold the promise that a series of possible future scenarios could be developed. With improved models of the processes that lead to the diffusion of knowledge and the evolution of the communities of science, new and emerging areas of discovery could be identified and targeted for accelerated assistance. For example, researchers have begun to look at gaps in the "Idea Innovation Network". The Idea Innovation Network divides research activities into six different innovation arenas and their relatedness within a particular industrial sector (see box below). Gaps in our understanding of this include the roles of low- versus high-risk science, as well as small versus large-scale science.[17]

A similar effort has gone into developing a complex systems model of technological evolution, focusing on low-carbon energy technologies. Many agencies, such as DOE, NIH, and NSF are funding new tools that capture data on citations and patents which can reveal areas of emerging innovation activity and the movement to market, offering tantalizing hints of real-time prediction of near-term discoveries. USDA Cooperative State Research, Education, and Extension Research (CSREES) and Forest Service (FS) are using logic models, which describe work inputs and outputs within an organization, to plan and assess their R&D portfolios and programs. Further, CSREES is requiring that logic models be included in proposals submitted to many of its programs. USDA Economic Research Service (ERS) is using environment scanning, commonly used by companies to gain factual and subjective information on business environments they are considering entering, to poll external stakeholders on future program directions. NASA uses decadal surveys and strategic roadmaps to plan, relying heavily on independent assessments, thereby identifying and prioritizing promising scientific goals, missions, and programs.

Finding: Agencies are using very different approaches and tools designed to develop scenarios that anticipate the effects of discovery and innovation. Many agencies are not doing this at all. There is very little communication across agencies, and little evaluation of the strengths or benefits of different approaches. No agency reported using approaches similar to those developed by the Federal Reserve, which expended considerable effort to create a complex econometric model based on the best available models, data, and tools to understand the impact of different interventions on a complex set of outcomes.[18] In addition, there is little transparency in the analytical process.

DEFINITION: IDEA INNOVATION NETWORKS
These networks exist at the level of an industrial sector and market sector, and each network has six different functional arenas in which various types of innovative processes occur. The six research arenas are basic research, applied research, research about product development, research on manufacturing processes, research on quality control, and research about the commercialization and marketing of products. Each of these functional arenas has its own highly trained workers, dedicated research funds, and specific outputs. An idea innovation network is defined as the research activities in each of the six arenas and the connectedness within and among these arenas in a particular industrial sector.

Hage, Jerald and J. Roger Hollingsworth. 2000. "A Strategy for the Analyses of Idea Innovation Networks and Institutions" Organization Studies (Special Issue: The Institutional Dynamics of Innovation Systems) 21(5): 971-1004.

Question 6: Is It Possible To Describe The Impact Of Discovery On Innovation?

The current state of the art in describing the impact of discovery, typically cast as R&D or technology, rests on the results of econometric studies, surveys, case studies, and retrospective analyses.

Econometric studies include the macroeconomic growth models pioneered by Robert Solow[19], which show the equilibrium growth path for an economy with an assumed endowment of technology, but pay little attention to the development of technology or how it gets used (innovation). The Solow models have been embellished and expanded by others[20, 21], however, these models are limited by their treatment of discovery as an exogenous "black box" rather than as part of a larger ecosystem of innovation. This kind of aggregated approach, which has been implemented by the European Union,[22] is not flexible enough to capture the complexity of the feedback mechanisms which the nascent literature indicates lies at the core of innovation.

Surveys are heavily used by a number of agencies. EPA relies on a combination of partner surveys, research citations in regulatory and other documents, and bibliometric analyses to inform their broader program reviews that assess research impact. Other agencies also track patents and papers. USDA-CSREES tracks publications of papers that result from its investments, as well as patents.[23] DOE has been exploring the use of a number of stochastic and linear models to understand the impact of scientific discovery.

Some agencies, such as NIST, prospectively estimate their impacts through standard benefit-cost analysis. Others, such as the CDC, conduct case studies summarizing selected research projects.[24] The CDC has also used retrospective bibliometric analysis in the past, and is now moving to an internet-based information tracking system. Most agencies (NIH, DOE, NASA, EPA, USDA) track milestones and use peer-review, advisory committees, and survey instruments to assess impacts. Other agencies such as USGS have explored the importance and value of improved scientific information in land use decision making. A few agencies, such as

DOE and NIH, have begun to experiment with dynamic modeling and options modeling as ways to describe the impact of discovery.

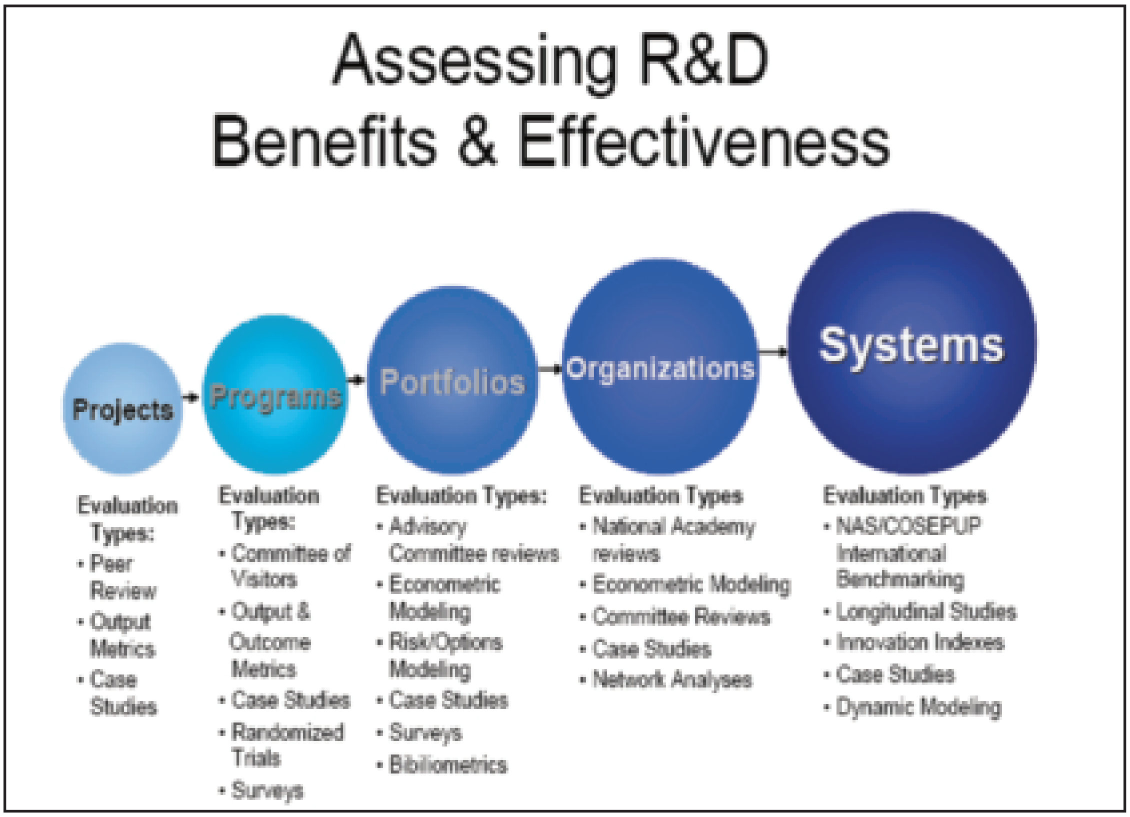
Finding: Agencies are using a wide variety of approaches to describe the impact of discovery. However, new approaches are being developed by the academic community that utilize new tools such as science mapping (correlating funding with research outputs), and new datasets such as the OECD international database of inter-organizational collaborative agreements. The Federal community still lacks a theoretical framework that it can use to assess the impact of science and technology policies on discovery and resultant social welfare outcmes.

DEFINITION – SCIENTIFIC DISCOVERY:
Scientific discovery may be described as the observation of new phenomena, new actions, or new events and providing new reasoning to explain the knowledge gathered through such observations with previously acquired knowledge from abstract thought and everyday experience. In scientific research, exploration is one of three purposes of research, the other two being description and explanation. Discovery is made by providing observational evidence and attempts to develop an initial, rough understanding of some phenomenon.

http://en.wikipedia.org/wiki/Discovery_%28observation%29

Question 7: What Are The Determinants Of Investment Effectiveness?

Federal agencies are accountable for the effectiveness of their R&D investments. This requirement has been made explicit by OMB through the use of R&D Investment Criteria and the PART. As a result, some agencies have developed a variety of tools to assess the effectiveness of their investments, while others still lack such tools. In terms of assessing the success of individual projects, agencies have made tremendous strides.



Different agencies use different tools to make policy and investment decisions – the method depends on the scope and size of the science involved. ***Types of Evaluation Methods for Assessing R&D Benefits and Effectiveness for Various Scales of R&D Investment***, U.S. Department of Energy.

Finding: Techniques used by Federal agencies to determine program effectiveness span the spectrum from those in the pilot stages to those that are mature. A list of these approaches as revealed by the SOSP ITG questionnaire include:

- *Growth Accounting*— used to better generate estimates of the Nation's productivity performance in terms of contributing factors and outputs.

- *Knowledge Economy*— these composite knowledge indicators are used to improve investment decisions for R&D, education, and capital resources.

- *Financial Reporting*—these reports are used to provide a balanced scorecard of physical as well as intangible assets.

- *Valuation of Innovation*—business executives and financial markets (to better value R&D activity and related intangibles) estimate financial results, improve long term stock market valuations, and predict outcomes.

- *System Dynamics*—expand the range of "real-time" innovation metrics to help build more robust system dynamics models and policy simulations.

- *General Purpose Technology (GPT)* — improved analysis of the strategic contribution of GPT's may set the stage for incremental innovation and have the inherent potential for pervasive application in a wide variety of industries

- *Tech-led Regional Development and Clusters*—used to shift the emphasis from strengthening inputs to the innovation infrastructures toward improving the efficiency, rate, and output of innovation.[25]

While these tools are extremely useful for assessing program effectiveness, the evaluation of complex portfolios (such as those managed by NSF, DOE or NIH) remains difficult. Agencies are keenly aware of the deficiencies in their approaches. One agency, when responding to the ITG's questionnaire, noted: "Waiting to count publications, for example, is too late to affect the real-time assessment of a particular grant." Another noted: "We need a great deal more outcome data. The data currently available are inadequate for program evaluation purposes. Resources are needed to improve Federal and other data collections systems".

Of course, evaluation approaches vary even within an agency, depending on the nature of the needs, as the Figure demonstrates. For details, see the "Current and Potential Toolkit For Science and Innovation Policy" section.

Theme 2 Recommendations

The ITG recommends that a Federal Innovation Framework, as described in Theme 1, be created to accelerate the development of the nascent community of science policy researchers and practitioners through interagency coordination and targeted investments. Led by OSTP, this working group could assist each agencies' specific science policy analysis capabilities, while coordinating efforts to identify and promote best practices and information sharing around science policy and R&D investment management. Specific recommendations include:

- Agencies (such as NIH, NSF, DHS, CDC, VA, NASA, USGS, and DOE) should work together to develop a pilot data infrastructure that captures key data about their respective scientific communities. The development would include an assessment of the validity of the new visualization techniques to describe the changing structure of science.
- Agencies should work together to develop pilot standards for identifying ways of measuring the value of knowledge, which could then be adapted to the missions of individual agencies.
- Agencies should work together to develop standard approaches for using bibliometrics to assess science impact.

The academic research community should continue to be supported to perform the best research to develop new analytical tools, methods, and metrics to support the emerging science of science policy.

Theme 3: Using the Science of Science Policy to Address National Priorities

By developing the core data, models, and tools that will be necessary to answer the 10 Scientific Challenges addressed in this Roadmap, significant advances in economics, sociology, psychology and political science could be made that would benefit all of society.

Advances in the social and economic sciences provide the foundation for the science of science policy and should be leveraged to develop decision support tools that policy makers could use when grappling with extraordinarily complex national challenges. Decisions to invest in science are, by necessity, made in the context of other investment decisions (such as investments in defense and transportation infrastructure), and the current absence of appropriate analytical tools limit the careful analysis of the relative costs and benefits of such investments. The absence of tools stands in sharp contrast to the intricate econometric models used by the financial community to understand trade and industrial phenomena. These econometric tools have developed over decades and are just now reaching maturity as the field of economics has matured; in similar manner, it is expected that tools and models for science policy should develop, as the field matures.

The Human Genome Project was a concerted Federal effort in science that resulted in interagency cooperation to solve a national challenge.

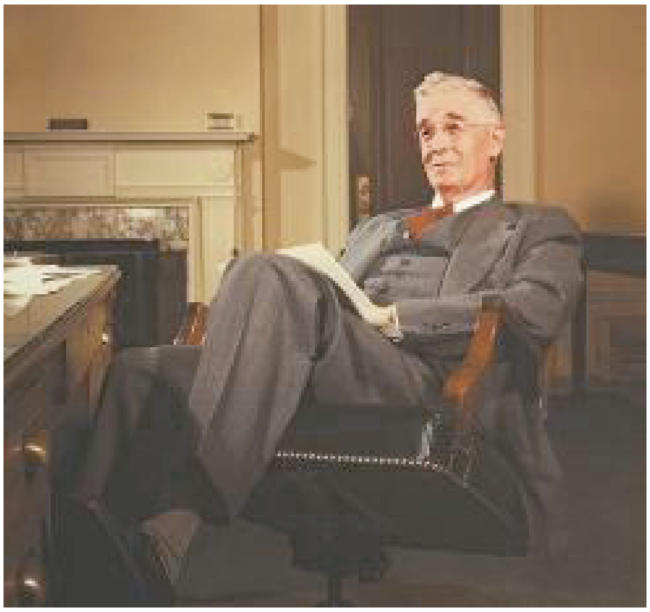
U.S. Department of Energy, http://genomics.energy.gov/

The development of a Federal Innovation Framework could be used not only to assess the state of the art in SoSP and its relevant tools as described, it could also be utilized to perform analyses relevant to national priorities. Examples include addressing climate change technology options, agricultural policy that is impacted by the decision to pursue biofuels, and understanding the implications of improved health care in the U.S. on social support networks such as Medicare and Medicaid.

DEFINITION – INNOVATION INFRASTRUCTURE
Innovation infrastructure is the physical and policy infrastructure that supports innovators. Innovation infrastructure includes information networks, intellectual property protections, business regulations, and structures for collaboration among innovation stakeholders. These supporting infrastructures should be adaptive as the needs for scientific innovation evolve, requiring informed policy that evolves apace.

Innovate America, National Innovation Initiative Report, Council on Competitiveness, 2005, http://www.compete.org/images/uploads/File/PDF%20Files/NII_Innovate_America.pdf.

Question 8: What Impact Does Science Have On Innovation And Competitiveness?



Vannevar Bush, President Science Advisor, helped establish the science and technology policy that enabled the U.S. Federal government to play a central role in the creation of the world's leading innovation economy.

http://www.carnegieinstitution.org Yearbook

Vannevar Bush, in his seminal 1945 treatise, "Science, The Endless Frontier," wrote: "New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science." Bush's treatise helped shape U.S. Federal government policy on science and technology and gave great support for the notion that innovation in science and technology is a key driver of U.S. national economic prosperity and national security.

In the last half century, economists and social scientists have attempted to document the impact of the scientific enterprise on U.S. innovation and competitiveness, with mixed results. At the macro level, economists such as Robert Solow (who won the Nobel Prize in Economics for his work on the impact of innovation on economic growth) have developed widely accepted theories that explain how investments in science and technology have a positive impact on economic growth. There are disputes about the rate of growth and other factors, but there is no dispute that the impact is positive. At the micro level, economists such as Erik Brynjolfsson have documented the positive impact of information technology on organizations and firm performance[1]. This level of analysis is helpful because it provides comfort to Federal policy makers that their investment strategy is sound, but macro level econometric models cannot answer the basic question, *how much funding is enough*?

For example, policy makers do not have rigorous and quantitative tools that explain how various technology streams could reduce U.S. energy consumption, or whether or not investments in rare diseases that afflict small populations are more important to society than investments in common diseases, such as HIV or cancer, that require long-term investments with uncertain prospects for success.

There is a considerable literature on impact evaluation in the social sciences that is related to this problem set confronted by the science of science policy community. There are also new developments in the ways of collecting data on complex inputs, such as the generation of ideas through tracking citations, as well as collecting information on the transmission of ideas through social networks and scientific communities. The increasing availability of administrative data, combined with advances in privacy protection, could allow for the examination of the impact of different types of tax credits on businesses, or illuminate hiring patterns.

Finding: The ITG finds that there is a real opportunity to develop new tools and data sets that could be used to quantify the impact of the scientific enterprise thus far on innovation and competitiveness. These impacts could include the generation of knowledge, the health of the universities receiving funding, the growth of the STEM workforce, or the growth and survival of those businesses and their workforces most closely linked to the scientific enterprise.

1 See, for example, Aral, S., Brynjolfsson, E. and Wu, D.J., Which Came First, IT or Productivity? The Virtuous Cycle of Investment and Use in Enterprise Systems , MIT Center for Digital Business Working Paper, (October, 2006).

Question 9: How Competitive Is The U.S. Scientific Workforce?

The dominance of the U.S. scientific enterprise is dependent on the quality of its scientific workforce. Our national competitiveness in science has been enhanced by the many foreign students who come to U.S. universities, as well as by the many skilled STEM workers who move to the U.S. from other countries. However, U.S. scientific dominance may be threatened by the ability of other countries to train their own technical workforce, as well as the ability of businesses to tap into the innovative capacity of a global scientific community and encourage technical workers from the U.S. to relocate to nations such as China and India.

There has been considerable policy debate about the quality of the STEM workforce but arguments supporting either side of the issue are hindered by a lack of longitudinal data on the post secondary STEM workforce. Questions about this workforce include: what happens to them when they graduate; where do they get jobs; and what are their labor market trajectories? Industries accustomed to the free flow of technical workers sometimes find that national security concerns impede their ability to recruit and retain international workers. Universities are now training large numbers of foreign scientists who return to their home countries.


Students in the lab - workforce development, NSF.

In addition, few direct measures of the global science and engineering (S&E) labor force exist. Recent analytical work has been done in the United States and Europe on “network analysis,” which could be used to measure the impacts of and reasons for the “high-skilled diaspora” that has been discussed in the science and engineering literature. Developing and extending the results of those network analysis studies could go a long way toward answering questions about labor market formation in S&E.

Finding: Many critical questions about the quality and global nature of the STEM workforce cannot be answered due to a lack of data. While the models and tools exist to study flows of workers within and across disciplines and nations, lack of data means that the science policy community cannot answer important questions about the scientific enterprise.

Question 10: What Is The Relative Importance Of Different Policy Instruments In Science Policy?

The primary policy instrument that the U.S Federal government wields for science policy is broad Federal investment in key areas of science and technology. As a result, the U.S. has invested trillions of dollars over six decades in university research, scientific workforce development, national laboratory infrastructure, major scientific instruments and other areas. This has resulted in an unrivaled, world class scientific infrastructure that will be extremely difficult for any other nation to duplicate. This massive investment in science and technology by the Federal government is perhaps the key U.S. competitive advantage in the emerging international innovation competition. This competitive advantage has not gone unnoticed, which helps explain the drive by China, Korea and other Asian countries to make major national investments in science and technology and the decision by the European Union to triple its rate of investment in science and technology.

Investment in science and technology, however, is only one of the policy instruments available to science policy makers; others include fostering the role of competition and openness in the promotion of discovery, the construction of intellectual property systems, tax policy, and investment in a STEM workforce. However, the probable impact of these various policies and interventions is largely unknown. This lack of knowledge can lead to serious and unintended consequences. For example, Federal efforts to increase industrial innovation through university technology transfer programs has led to concerns that universities are now focusing too much on near-term research and too little on their traditional strength, which is long-term and basic research. The recent doubling of investment at NIH has created concerns within the medical community about the impact these investments have had on the production of PhDs and tenured faculty at universities.

Finding: There has been very little investment in the study of alternative science policy instruments either in the United States or in other countries. While the models and tools exist to examine the effectiveness of different approaches, there are gaps in the analytical structure, the data infrastructure, and in the ways in which information can be conveyed to policy makers.

Theme 3 Recommendations

The ITG recommends investing in data collection, analytical tools, and ways to present complex information.

Form **6765** — **Credit for Increasing Research Activities** — ▶ Attach to your tax return. — OMB No. 1545-0619 — **2007** — Attachment Sequence No. **81**

Department of the Treasury
Internal Revenue Service

Name(s) shown on return — **Identifying number**

Section A—Regular Credit. Skip this section and go to Section B or C if you are electing or previously elected (and are not revoking) the alternative incremental credit or the alternative simplified credit, respectively.

1 Certain amounts paid or incurred to energy consortia (see instructions) — 1
2 Basic research payments to qualified organizations (see instructions) — 2
3 Qualified organization base period amount — 3
4 Subtract line 3 from line 2. If zero or less, enter -0- — 4
5 Wages for qualified services (do not include wages used in figuring the work opportunity credit) — 5
6 Cost of supplies — 6
7 Rental or lease costs of computers (see instructions) — 7
8 Enter the applicable percentage of contract research expenses (see instructions) — 8
9 Total qualified research expenses. Add lines 5 through 8 — 9
10 Enter fixed-base percentage, but not more than 16% (see instructions) — 10 %
11 Enter average annual gross receipts (see instructions) — 11
12 Multiply line 11 by the percentage on line 10 — 12
13 Subtract line 12 from line 9. If zero or less, enter -0- — 13
14 Multiply line 9 by 50% (.50) — 14
15 Enter the **smaller** of line 13 or line 14 — 15
16 Add lines 1, 4, and 15 — 16
17 Are you electing the reduced credit under Section 280C? ▶ Yes ☐ No ☐
If "Yes," multiply line 16 by 13% (.13). If "No," multiply line 16 by 20% (.20) and see the instructions for the schedule that must be attached. Members of controlled groups or businesses under common control: see instructions for the schedule that must be attached — 17

Section B—Alternative Incremental Credit. Skip this section if you are completing Section A or C.

18 Certain amounts paid or incurred to energy consortia (see the line 1 instructions) — 18
19 Basic research payments to qualified organizations (see the line 2 instructions) — 19
20 Qualified organization base period amount (see the line 3 instructions) — 20
21 Subtract line 20 from line 19. If zero or less, enter -0- — 21
22 Add lines 18 and 21 — 22
23 Multiply line 22 by 20% (.20) — 23
24 Wages for qualified services (do not include wages used in figuring the work opportunity credit) — 24
25 Cost of supplies — 25
26 Rental or lease costs of computers (see the line 7 instructions) — 26
27 Enter the applicable percentage of contract research expenses (see the line 8 instructions) — 27
28 Total qualified research expenses. Add lines 24 through 27 — 28
29 Enter average annual gross receipts (see the line 11 instructions) — 29
30 Multiply line 29 by 1% (.01) — 30
31 Subtract line 30 from line 28. If zero or less, enter -0- — 31
32 Multiply line 29 by 1.5% (.015) — 32
33 Subtract line 32 from line 28. If zero or less, enter -0- — 33
34 Subtract line 33 from line 31 — 34
35 Multiply line 29 by 2% (.02) — 35
36 Subtract line 35 from line 28. If zero or less, enter -0- — 36
37 Subtract line 36 from line 33 — 37

For Paperwork Reduction Act Notice, see instructions. Cat. No. 13700H Form **6765** (2007)

R&D tax credits constitute one type of policy instrument. Form 6765, Credit for Increasing Research Activities, Internal Revenue Service

- Several core datasets should be established and made available to both the research and policy community.

    - The first of these is a longitudinal dataset on businesses, oversampling those businesses which are critical to American competitiveness, such as high tech, biotech, and multinational firms. Existing administrative data should be used to keep the costs manageable and the sample scientific.

    - The second is a longitudinal dataset on the STEM workforce. Although the original dataset could have a survey basis, every effort should be made to exploit longitudinal administrative records, and to partner with other countries in order to capture the long term dynamic adjustments of workers.

    - The link between workers and firms must be tracked through administrative records and other modes of data collection so that the relationship between the humans, who are the sources of innovative ideas, and the firms, who bring the ideas to market, can be analyzed.

- The Federal Innovation Framework must include feedback loops that analyze the impact of various policy instruments. This will require cooperation with a wide variety of other Federal agencies, including the Department of Treasury, the Census Bureau and the major Federal statistical agencies to understand the effects of tax policy, labor policy and other Federal efforts that impact science policy.

Summary of Recommendations

Theme 1: Understanding Science & Innovation

Science Question	**Why it matters**	**Recommendations and Actions**
What are the behavioral foundations of innovation?	Understanding the behavior of individuals and organizations is fundamental to developing estimates of the importance of the key factors in the innovation process.	• An NSTC Working Group should regularly perform portfolio analyses of the full spectrum of SoSP across the Federal government and provide advice to the President's Science Advisor about the results of those analyses. These analyses are tentatively described in this report as a "Federal Innovation Framework," which analyses how Federal investments and policy decisions affect the Nation's system of innovation. • NSF and other agencies should continue to support the development of a theoretical foundation through existing programs of investigator-initiated research. Workshops and informational websites can facilitate that dialog. • Individual agencies should work together to identify a core suite of ways to measure and describe technology adoption and diffusion. They should also develop ways in which the many scientific communities of practice for each agency could be described and analyzed. Working subgroups such as these would be responsible generating a report to the larger Working Group. • Federal agencies could work with international counterparts to develop a consistent approach to the Science of Science Policy that transcends national boundaries, potentially through the OECD or international meeting symposia.
What explains technology adoption and diffusion?	Identifying the drivers of technology adoption is at center of the discovery to innovation cycle.	
How and why do communities of science and innovation form and evolve?	Understanding scientific communities and their associated social networks are a key to understanding the value of knowledge production. Involving scientists is necessary to guide the development of the research questions.	

Theme 2: Investing in Science and Innovation

Science Questions	Why it matters	Recommendations
What is the value of the Nation's public investment in science?	Developing a way to describe, or think about describing, outcome measures is critical to moving beyond anecdotal evidence.	• Agencies (such as NIH, NSF, DHS, CDC, VA, NASA, USGS, and DOE) should work together to develop a pilot data infrastructure that captures key data about their respective scientific communities. The development would include an assessment of the validity of the new visualization techniques to describe the changing structure of science. • Agencies should work together to develop pilot standards for identifying ways of measuring the value of knowledge, which could then be adapted to the missions of individual agencies. • Agencies should work together to develop standard approaches for using bibliometrics to assess science impact. • The academic research community should continue to be supported to perform the best research to develop new analytical tools, methods, and metrics to support the emerging science of science policy.
Is it possible to "predict discovery"?	A common framework must be adopted so that the question can be discussed (if not answered).	
Is it possible to describe the impact of discovery on innovation?	The taxpayers, Congress and OMB will hold the scientific community either implicitly or explicitly accountable for Federal research expenditures.	
What are the determinants of investment effectiveness?	Federal scientific agencies must be able to answer this question in making resource allocation decisions	

Theme 3: Using the Science of Science Policy to Address National Priorities

Science Question	Why it matters	Recommendations and Actions

What impact does science have on innovation and competitiveness?	Understanding the ways in which the scientific enterprise affects firm competitiveness, as well as the wages and jobs of Americans as described by the America COMPETES Act.	• Several core datasets should be established and made available to both the research and policy community.
		  • The first of these is a longitudinal dataset on businesses, over-sampling those businesses which are critical to American competitiveness, such as high tech, biotech, and multinational firms. Existing administrative data should be used to keep the costs manageable and the sample scientific.
		  • The second is a longitudinal dataset on the STEM workforce. Although the original dataset could have a survey basis, every effort should be made to exploit longitudinal administrative records, and to partner with other countries in order to capture the long term dynamic adjustments of workers.
		  • The link between workers and firms must be tracked through administrative records and other modes of data collection so that the relationship between the humans, who are the sources of innovative ideas, and the firms, who bring the ideas to market, can be analyzed.
		• The Federal Innovation Framework must include feedback loops that analyze the impact of various policy instruments. This will require cooperation with a wide variety of other Federal agencies, including the Department of Treasury, the Census Bureau and the major Federal statistical agencies to understand the effects of tax policy, labor policy and other Federal efforts that impact science policy.

How competitive is the U.S. scientific workforce?	National competitiveness in science is fundamentally affected by the ability of STEM workers to move across countries, as well as the ability of businesses to tap into the innovative capacity of a global scientific community.	
What is the relative importance of different policy instruments in science policy?	At a time of limited resources, Federal resources must be tightly targeted. As a result, policy makers need to understand the effectiveness of different policy instruments, such as the role of competition and openness in the promotion of discovery; the role of policy instruments, such as earmarks, peer review, and intellectual property systems; the importance of tax policy and the ways to investment in the appropriate human resources.	

Current and Potential Toolkit For Science and Innovation Policy

An obvious question is: "What toolkit of models, tools and metrics is currently available for policy makers when making science policy decisions, and what could be available with additional focus on the development of SoSP?" In order to answer this question, the ITG relied on the literature synthesis, the questionnaire, and its own experience. It first identified the models, tools and metrics currently being used by Federal agencies, which included:

Models and Tools:	
Quantitative Analysis	• Deterministic Models: Econometric; Risk Modeling; Options 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

The ITG then identified the dimensions along which the methods, tools and metrics had value for science policy as well as the dimensions for assessing the potential cost if any investment were to be required to bring them to full use. Five criteria were identified, three associated with the potential value of the element: Relevance for Science Policy, Breadth of Use, Scientific Rigor; and three associated with the potential cost: Maturity of the Method or Tool, Availability and Quality of Data Required.

Relevance to Vision:	The degree to which the element provides a significant contribution to resolving one or more of the 10 Scientific Challenges identified by the ITG.
Breadth of Use:	The extent of the adoption of the element in the Federal or academic science policy context.
Scientific Rigor:	The quality of the scientific foundation of the element, in terms of publications, scientific openness, size of community and reproducibility.
Maturity of the Method or Tool:	The degree to which the element is used in the Federal or academic science policy context.
Availability and Qualityof Data Required:	The practicality of using the element to develop the empirically based platform for decision making that is the goal of science policy.

In order to provide a visualization of state of play of each of these models, tools and metrics, the ITG then created two grids mapping each element. Green signifies that the element is currently fulfilled with respect to the criterion; yellow signifies that the element is on the way to fulfilling the criterion; red signifies that there are substantial gaps.

MODELS/TOOLS		Theme	Potential Value Value of Investment			Potential Cost		Main Missing Element
			Relevance to Vision	Breadth of Use	Scientific Rigor	Maturity	Access to Inputs	
Quantitative Analysis	**Deterministic Models**							
	- Econometric	1,2,3	Green	Red	Green	Yellow	Yellow	**Data, Community**
	- Risk Modeling	2,3	Green	Red	Yellow	Yellow	Yellow	**Community**
	- Options Modeling	2,3	Green	Red	Yellow	Yellow	Red	**Community**
	- Cost Benefit	2	Green	Green	Yellow	Yellow	Red	**Community**
	- Cost Effectiveness	2	Green	Green	Yellow	Yellow	Red	**Community**
	Stochastic Models							
	- Agent Based	2	Green	Red	Green	Red	Red	**Data, Community**
	- System Dynamics	2	Green	Yellow	Green	Yellow	Green	**Community**
Qualitative Analysis	- Case Studies	1, 2	Green	Green	Green	Green	Green	**Community**
	- Peer/Expert Review	2	Green	Green	Green	Green	Green	**Community**
	- Delphi	2	Green	Yellow	Red	Green	Yellow	**Community**
	- Strategic/Logic	2	Yellow	Green	Red	Green	Yellow	**Community**
Visualization Tools	- Network Analysis	2,3	Green	Red	Green	Red	Red	**Data, Community**
	- Visual Analytics	2, 3	Green	Red	Green	Yellow	Red	**Community**
	- Science Mapping	2,3	Green	Red	Red	Red	Red	**Data, Community**
	- Scientometrics	2, 3	Green	Green	Red	Yellow	Red	**Data, Community**
Data Collection Tools Tools	- Survey	1,2,3	Green	Green	Green	Green	Yellow	**Data, Community**
	- Web Scraping	1, 2,3	Green	Red	Red	Red	Yellow	**Data, Community**
	- Administrative Data	1, 2,3	Green	Red	Green	Green	Yellow	**Community**
	- Data Mining	1,2,3	Green	Red	Yellow	Red	Red	**Data, Community**

METRICS		Theme	Potential Value Value of Investment			Potential Cost		Main Missing Element(s)
			Relevance to Vision	Breadth of Use	Scientific Rigor	Maturity	Availability of Inputs	
Outcomes	**Scientific/Micro Level**							
	Innovation	1,2,3						**Data, Community**
	Competitiveness	3						**Community**
	Knowledge Increase	2,3						**Data, Community**
	Program/Portfolio:							
	Effectiveness	1,2,3						**Community**
	Value	2,3						**Data, Community**
	Systems Level:							
	Productivity	1,2,3						**Community**
	Quality of Life	3						**Community**
	Workforce Character-istics	2,3						**Data, Community**
	GDP	1,2,3						**Community**
Budget and Performance	Earned Value	2						**Community**
	Process Metrics	2						**Data, Community**
	Efficiency	2						**Community**
	Marginal Cost	2						**Community**
Inputs	**Bibliometrics:**							
	Citations	1,2,3						**Data, Community**
	Patents	1,2,3						**Community**
	Scientific Papers	1,2,3						**Data, Community**
	Community/Network:							
	Network Value	1,2,3						**Community**
	Effectiveness	1,2,3						**Community**
	Structure	1,2,3						**Data, Community**
	Workforce	1,2,3						

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ACRONYMS

ATP	Advanced Technology Program (NIST)
CERN	European Organization for Nuclear Research (Conseil Européen pour la Recherche Nucléaire)
CDC	Centers for Disease Control and Prevention
AMERICA COMPETES ACT	America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act, 2007
COSEPUP	Committee on Science, Engineering and Public Policy
CRIS	Current Research Information System (USDA)
CSREES	Cooperative State Research, Education, and Extension Research (USDA)
DHHS	U.S. Department of Health and Human Services
DHS	U.S. Department of Homeland Security
DOC	U.S. Department of Commerce
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOEd	U.S. Department of Education
DOI	U.S. Department of Interior
DOT	U.S. Department of Transportation
EPA	Environmental Protection Agency
ERS	Economic Research Service
FS	Forest Service (USDA)
GPRA	Government Performance Results Act
GPT	General Purpose Technology
IRS	Internal Revenue Service

ITG	Interagency Task Group
NAS	National Academy of Sciences
NASA	National Aeronautics & Space Administration
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NSTC	National Science and Technology Committee
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
PART	Program Assessment Rating Tool
R&D	Research and Development
ROI	Return on Investment
S&E	Science and Engineering
S&T	Science and Technology
SciSIP	Science of Science and Innovation Policy
SBE	Social, Behavioral, and Economic Sciences
SoSP	Science of Science Policy
STEM	Science, Technology, Engineering, and Mathematics
USDA	U.S. Department of Agriculture
VA	U.S. Department of Veterans Affairs

Appendix A - Charter

National Science and Technology Council
Committee on Science
Committee on Homeland and National Security
Subcommittee on Social, Behavioral and Economic Sciences
Interagency Task Group on Science of Science Policy

Charter

A. Preamble

The Interagency Task Group on Science of Science Policy (hereafter referred to as the "Task Group") is hereby established by the Subcommittee on Social, Behavioral and Economic Sciences (SBE). The Task Group serves as part of the internal deliberative process of the Subcommittee, which provides guidance and direction.

B. Purpose and Scope

Currently, science policy discussions are dominated by advocates for particular scientific fields or missions and policy decisions are frequently based upon past practice or data trends that may be out of date or have limited relevance to the current situation. We know that past investments in basic scientific research have had an enormous impact on innovation, economic growth and societal well-being, but we do not have the capacity to predict how best to make and manage future investments so as to exploit the most promising and important opportunities.

While some fields benefit from the availability of real-time data and computational models which allow for predictive analyses, science policy does not benefit from a similar set of tools and modeling capabilities. It is imperative to advance the scientific basis of science policy, through the development of data collection, analyses and modeling tools, so that we can make future policy decisions based on sound science and informed judgment. We must also develop both quantitative and qualitative tools to enable the collection of real-time data and to facilitate better retrospective analysis of the impact of federal investments on scientific discovery and innovation, the economy and society. In this way, we can learn from past investments and refine the accuracy of our predictive models.

In order to advance the academic discipline of the science of science policy, the SBE subcommittee is establishing a Task Group that will develop a roadmap for federal efforts directed toward the long-term development of a science of science policy.

C. Objectives

In formulating the roadmap, the Task Group will pursue the following objectives:

- Assess and inventory the current status of Federal and international efforts in the science of science policy and determine where gaps exist.
- Determine the sources of data and identify tools for modeling and analysis that have the potential to contribute to improved indicators and metrics for national and international research and development (R&D) investments.

- Identify and coordinate Federal funding opportunities to develop tools, theories and methodologies that will advance the science of science policy, and recommend joint research, modeling, and evaluation projects that would enable Federal agencies to collaborate, coordinate and leverage resources and efforts.
- Develop linkages between these opportunities and the activities of other groups and agencies that are also interested in understanding and modeling the national and global R&D enterprise and in predicting and evaluating the impacts of R&D investments, highlighting path breaking techniques that might contribute to deeper understanding and marketable innovations.
- Develop a roadmap, that incorporates the results of the government-wide survey and, where appropriate, consultation with private sector experts. This roadmap would offer a variety of strategies to address the current gaps in theory, data, methodologies, and models.
- Periodically assess progress, determine whether course corrections are needed and submit progress reports to the SBE subcommittee on a regular basis.

D. Membership

The following agencies are represented on the Interagency Task Group on Science of Science Policy:

1. Department of Energy (co-chair)
2. National Science Foundation (co-chair)
3. Department of Agriculture
4. Department of Commerce
5. Department of Defense
6. Department of Education
7. Department of Health and Human Services
8. Department of Homeland Security
9. Department of the Interior
10. Department of State
11. Department of Transportation
12. Department of Veterans Affairs
13. National Aeronautics & Space Administration
14. National Institutes of Health
15. National Institute of Standards and Technology
16. Office of Science and Technology Policy
17. Office of Management and Budget

Other organizations may participate as appropriate.

E. Interactions with Other Groups

The Task Group may interact with other Federal government organizations and NSTC bodies as required in the performance of its work. The Task Group may also interact with Federal advisory bodies such as the National Science Board (NSB) and the President's Council of Advisors on Science and Technology (PCAST). The Task Group may interact with and receive *ad hoc* information and advice from private sector groups as consistent with the Federal Advisory Committee Act.

F. Termination

Unless renewed by the chairs of the SBE Subcommittee prior to its expiration, the Interagency Task Group on Science of Science Policy shall terminate no later than March 31, 2009.

G. Determination

I hereby determine that the formation of the Interagency Task Group on Science of Science Policy is in the public interest in connection with the performance of duties imposed on the Executive Branch by law, and that such duties can best be performed through the advice and counsel of such a group.

Approved:

David Abrams, NIH, (Co-Chair)
Subcommittee on Social, Behavioral and Economic Sciences

10/26/06.
Date

David Lightfoot, NSF, (Co-Chair)
Subcommittee on Social, Behavioral and Economic Sciences

17 August 2006
Date

Joseph Kielman, DHS, (Co-Chair)
Subcommittee on Social, Behavioral and Economic Sciences

October 26, 2006
Date

Apppendix B – Science Magazine Editorial

EDITORIAL

Wanted: Better Benchmarks

How much should a nation spend on science? What kind of science? How much from private versus public sectors? Does demand for funding by potential science performers imply a shortage of funding or a surfeit of performers? These and related science policy questions tend to be asked and answered today in a highly visible advocacy context that makes assumptions that are deserving of closer scrutiny. A new "science of science policy" is emerging, and it may offer more compelling guidance for policy decisions and for more credible advocacy.

All developed and many developing nations today have accepted the need to support technical education and research as keys to future economic strength. Studies from the 1990s show that U.S. investment in R&D development led to greater economic productivity, and that information technology, in particular, has been a major factor in sustaining U.S. productivity growth. The question is not whether R&D investments are important, but what investment strategies are most effective in the rapidly changing global environment for science. Here, ideas diverge.

Take the issue of the technical workforce. Sharply differing opinions exist regarding the production of U.S. scientists to meet possible impending shortages.* The differences turn on the interpretation of "benchmark" data regarding the numbers of degree holders produced in the United States and other countries, particularly China and India. In the latter countries, the rates of growth in the numbers of scientists are high, although actual numbers are small relative to those in the United States. Advocates for increased production of U.S. scientists point to our low graduation rates, whereas critics emphasize limited short-term job opportunities for graduates and postdocs. Resolution of this issue requires a broader understanding of socioeconomic factors in a number of nations that would allow us to attach probabilities to different future scenarios. Optimal strategies for large mature economies such as that of the United States will doubtless differ from those for smaller or developing economies. Here, as elsewhere in policy debates, the benchmarks do not speak for themselves.

The data we choose to collect do say something about the framework in which we understand the relations among science, government, and society. Our customary reliance on historical trends in national data, however, creates an inertia that causes data categories to lag far behind changes in the dynamic socioeconomic framework, now evolving internationally. We know that there is a complex linkage between workforce issues and other economic variables. Technical workforces in different countries are increasingly interdependent in a way that makes single-country data unreliable for workforce forecasts.

Globalization and changing modes of science that have blurred disciplinary distinctions have undermined the value of traditional science and engineering data and their conventional interpretations. The old budget categories of basic and applied R&D, still tracked by the U.S. Office of Management and Budget, do not come close to capturing information about the highly interdisciplinary activities thought to fuel innovation. A 1995 U.S. National Research Council (NRC) committee chaired by Frank Press took a step toward data reform when it introduced the combined category of "federal science and technology," declaring that "the linear sequential view of innovation is simplistic and misleading." More attention, however, is needed to definitions and models that suit current needs of policy. A recent report from the NRC Committee on National Statistics found that "the structure of . . . data collection is tied to models of R&D performance that are increasingly unrepresentative of the whole of the R&D enterprise." Further, "It would be desirable to devise, test and, if possible, implement survey tools that more directly measure the economic output of R&D in terms of short-term and long-term innovation."†

Relating R&D to innovation in any but a general way is a tall order, but not a hopeless one. We need econometric models that encompass enough variables in a sufficient number of countries to produce reasonable simulations of the effect of specific policy choices. This need won't be satisfied by a few grants or workshops, but demands the attention of a specialist scholarly community. As more economists and social scientists turn to these issues, the effectiveness of science policy will grow, and of science advocacy too.

John H. Marburger III

John H. Marburger III is director of the Office of Science and Technology Policy, Executive Office of the President of the United States, in Washington, DC.

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Report on the Science of Science Policy to the

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Committee on Science
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Office of Science and Technology Policy

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