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Editors' Introduction

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1. Introduction

Federally funded basic and applied scientific research has had an enormous impact on innovation, economic growth, and social well-being—but some has not. Determining which federally funded research projects yield results and which do not would seem to be a subject of high national interest, particularly since the government invests more than $140 billion annually in basic and applied research. Yet science policy debates are typically dominated not by a thoughtful, evidence-based analysis of the likely merits of different investments but by advocates for particular scientific fields or missions. Policy decisions are strongly influenced by past practice or data trends that may be out of date or have limited relevance to the current situation. In the absence of a deeper understanding of the changing framework in which innovation occurs, policymakers do not have the capacity to predict how best to make and manage investments to exploit the most promising and important opportunities.

This lack of analytical capacity in science policy sits in sharp contrast to other policy fields, such as workforce, health, and education. Debate in these fields is informed by the rich availability of data, high-quality analysis of the relative impact of different interventions, and often computational models that allow for prospective analyses. The results have been impressive. For example, in workforce policy, the evaluation of the impact of education and training programs has been transformed by careful attention to issues such as selection bias and the development of appropriate counterfactuals. The analysis of data about geographic differences in health care costs and health care outcomes has featured prominently in guiding health policy debates. And education policy has moved from a "spend more money" and "launch a thousand pilot projects" imperative to a more systematic analysis of programs that work and that could promote local and national reform efforts.

Each of those efforts, however, has benefited from an understanding of the systems that are being analyzed. In the case of science policy, no such agreement currently exists. Past efforts to analyze the innovation system and the effect that federal research has on it have typically focused on institutions (federal agencies, universities, companies, etc.) and/or outputs (bibliometrics, patents, funding levels, production of PhDs, etc.). Absent is a systems-level construct that those institutions and outputs function within and a failure to understand that science and technology innovations are created not by institutions but by people, often working in complex social networks. This social dynamic, as well as the complex system-level interactions that result, is the subject of increasing academic scrutiny. *Science* magazine recently devoted a special section to "complex systems and networks" and referenced studies that examined complex socioeconomic systems, meta-network analysis, scale-free networks, and other analytical techniques that could be used to understand the innovation system.[1]

There is no fundamental reason why it is impossible to develop a science policy infrastructure that is similarly grounded in evidence and analysis as the workforce, health, and education domains. It is true that it is difficult: the institutional and political environment is complex, and the scientific discovery process is noisy and uncertain. Yet scientists should be excited, not deterred, by interesting but hard problems. And the history of the scientific advancement of other policy fields, with their studies of equally complex, noisy, and uncertain processes, is evidence that such efforts can succeed. Indeed, an interdisciplinary and international community of practice is emerging to advance the scientific basis of science policy through the development of data collection, theoretical frameworks, models, and tools. Its advocates envision that they can make future policy decisions based on empirically validated hypotheses and informed judgment.

There are fundamental reasons why it is becoming critical to develop such an evidence basis. One is that the White House is requiring agencies to do so: the joint Office of Management and Budget (OMB)/Office of Science and Technology Policy (OSTP) R&D Priorities memo issued in preparation for the FY2011 budget asks agencies to "develop outcome-oriented goals for their science and technology activities, establish procedures and timelines for evaluating the performance of these activities, and target investments toward high-performing programs. Agencies should develop 'science of science policy' tools that can improve management of their research and development portfolios and better assess the impact of their science and technology investments. Sound science should inform policy decisions, and agencies should invest in relevant science and technology as appropriate."[2]

Another is the looming imperative to document the impact of the nearly $20 billion in R&D investments embodied in the 2009 American Recovery and Reinvestment Act (ARRA). As Kei Koizumi points out in his chapter:

> Policymakers and evaluators can demonstrate easily the short-term economic effects of highway projects, of which there are billions of dollars worth in the Recovery Act; miles of asphalt poured, construction jobs created, and dollars introduced into local economies are well developed and easily produced measures for these investments. But what are the similar indicators for R&D investments?

Finally, the federal budget environment is likely to be extremely competitive for the foreseeable future. For a case to be made that investments in science have value relative to investments in education, health, or the workforce, an analytical and empirical link has to be made between those investments and policy-relevant outcomes. It is likely that that link will need to be made at multiple levels, since the macro link between R&D investments and economic growth is less convincing given the international evidence provided by the Japanese and Swedish experience.[3]

The federal agencies have begun to respond in two ways. One is to advance the theoretical and empirical research frontier through investigator-initiated research and new data collection. The second is to develop a federal community of practice among the seventeen science agencies involved in funding and administering science research.

In the former case, by mid-2010, the National Science Foundation's (NSF) Science of Science & Innovation Policy (SciSIP) program has made over ninety awards to social scientists and domain scientists. Ten of these are explicitly to use the ARRA stimulus as a way to examine the impact of science investments. The SciSIP program, through the Division of Science Resources Statistics, is also investing in the development and collection of new surveys to better inform the biennial Science and Engineering Indicators that are the basis for many policy decisions. This includes the new Business R&D Innovation Survey, which involves a complete redesign of the collection of R&D data, as well as the collection of innovation data.

In the second case, the National Science and Technology Council (NSTC) established, under the Social, Behavioral and Economic Sciences Subcommittee of the Committee on Science, a federal interagency task group on the Science of Science Policy interagency task group (SOSP ITG). This task group produced a road map for federal investments[4] and held a major international conference to highlight the findings in that road map.

Both the SciSIP program and the SOSP subcommittee have worked to foster a community of practice in a number of ways. The interagency group has organized major annual workshops on the implementation of science policy. A flourishing Listserv for the exchange of ideas and information has been established. And a new SOSP ITG/SciSIP website has been developed,[5] which has begun to provide an institutional basis for the development of a community of practice.

Of course, SOSP will not solve all science policy problems. It is intended to provide an intellectual framework upon which to make decisions. Indeed, as Goldston notes in his chapter:

> Science of Science Policy research will never be definitive, and Congress certainly always would and should draw on more than social science results in making its decisions. But there is plenty of room to improve the current state of affairs. In other areas of policy—macroeconomics, health care, environmental protection, to name a few—there is at least a semblance of an ability to project the outputs that will result from a given set of inputs, and a range of studies to draw on in discussing what has worked and what has failed. Reaching a similar level of understanding for science policy would be a welcome change, if hardly a panacea.

2. What the Science of Science Policy Entails

One of the aims of recent science of science policy activities is to develop the evidentiary basis for decision making by policy practitioners. There is also an organic development or reshaping of frameworks that pushes the boundaries of discovery in several fields and disciplines. While some debate whether the science of science policy is itself a discipline, there is wide agreement that there is a coalescing community of practice, which Feller, in his chapter, describes as a distributed association of policymakers (public and private) and researchers in a variety of fields and disciplines. This community is interdisciplinary and includes economics, engineering, the history of science, operations research, physics, political science, psychology, and sociology—and this list is not exhaustive.[6]

Federal science investments are driven by a political context, so the insights provided by political scientists are critical. Sapolsky and Taylor argue in their chapter that

> governments support the advancement of science and technology (S&T) mostly through their support of specific missions such as defense or health, and it is the politics of these missions, and the many contextual goals of government, that determines the rate and direction of its research and development investments.

> Governments can also affect the supply and demand conditions for science and technology outside the budgetary process via regulatory regimes, anti-trust, taxes, standards, etc.

Understanding the institutional and sociological environment is also critical, which is why sociologists make an important contribution. Powell, Owen-Smith, and Smith-Doerr indicate in their chapter that the "sociological science of science policy will theorize the link between the origins and later trajectories of social systems that will provide guidance for policymakers eager to intervene."

The economics of science policy is evolving beyond the initial constructs of macroeconomic linkages of inputs and productivity outcomes. Recent models utilize network analysis, bibliometric tools, and behavioral models to uncover latent relationships between the levels and rates of new scientific discoveries and the financial, human capital, organizational, and infrastructural inputs. While these models have historically made important contributions to policy decisions, Feller, Jaffe, and Freeman each caution in this volume that there is a need to understand the limitations of incentive structures and the requirement for careful empirical analysis to understand the system of scientific knowledge creation. Morgan, in his chapter, describes several systems modeling approaches, some of which originate outside of the social sciences. This migration and synthesis of ideas is precisely what creates a dynamic community of practice.

One area of the science of science policy that is often overlooked is that conceptualization of scientific development at the cognitive level. This very micro-examination of science policy is an emerging field, with collaboration between psychologists and engineers. Both disciplines are eager to understand the elements of the creative process. Gero describes frameworks that are used to understand creative cognitive processes, which may lead to new ideas that are marketable—innovation.

And, of course, science investments are ultimately predicated on contributing to innovation. Gault's chapter connects the work on the understanding of the science system to the need for work on delivering value to the market in the form of new goods and services and contributing to economic growth and social welfare.

3. The Need for the Handbook

Our review of the science policy curricula and syllabi in major research programs suggests that the emerging field lacks a cornerstone document that describes the current state of the art from both a practitioner and an academic point of view.

This handbook is intended to fill this gap by providing in-depth, scholarly essays authored by leading scientists and policy practitioners. We recognize that the field has multiple dimensions, and as such, this book is divided into three sections: theoretical issues, data and measurement, and policy in practice. Each author has been asked to provide a survey of a different aspect of the field, based on his or her domain expertise, which explores the plausible foundations of an evidence-based platform for science policy. The interdisciplinary nature of such a platform is evident from the nature of the questions asked by the authors: What are the essential elements of creativity and innovation, and how can they be defined to serve a truly scientific approach to policy? How can the technical workforce be quantified and modeled—what is its likely future, and how does it respond to the multiple forces that could be targets of policy? What is the impact of globalization on creativity and productivity in the science and engineering fields? What are the optimal roles of government and private investments in R&D, and how do their different outcomes influence R&D and innovative activities? As such, the contributors span a variety of disciplines, including economics, sociology, psychology, and political science.

It is worth noting that this handbook focuses on the science of science policy, which we feel is an understudied and underresearched area. There has been a great deal more research on the science of innovation policy, although, inevitably, some of that research is alluded to in different chapters. In addition, the focus is on U.S. federal science policy. We recognize that there are vibrant and important research areas that study both business R&D investments and regional science and innovation policies. And while managers of large research enterprises, such as Microsoft, and state agencies face substantial resource allocation decisions, our sense is that these decisions are fundamentally different from those in the federal science arena. And, although the science of science policy has garnered important attention on the international stage, it is impossible to do full justice to the complexity of the international issues—that deserves another volume in its own right

4. Concluding Goals

We hope that this handbook will contribute to the overarching goal for science policy, namely, the development of "common, high-quality data resources and interpretive frameworks, a corps of professionals trained in science policy methods and issues, and a network of high-quality communication and discussion that can encompass all science policy stakeholders."[7] As such, the purpose of the book is to provide

1. an overview of the current state of the science of science policy in four key social science areas: economics, sociology, political science, and psychology;
2. a perspective from the broader social and behavioral science community on the interesting scientific challenges and opportunities in this emerging field;
3. a review of the empirical—measurement and data—challenges inherent in describing and assessing the scientific enterprise; and
4. a perspective from the federal science and policy community on the critical science policy questions that create the demand for a science of science policy.

Notes

1. *Science*, July 24, 2009, pp. 405–432.

2. M-09-27, Memorandum for the Heads of Executive Departments and Agencies, August 4, 2009.

3. Julia Lane, "Assessing the Impact of Science Funding," *Science* 5 (June 2009), vol. 324, no. 5932, pp. 1273–1275, DOI: 10.1126/science.1175335.

4. "The Science of Science Policy: A Federal Research Roadmap," November 2008.

5. See http://scienceofsciencepolicy.net.

6. For example, all of these areas are represented among the SciSIP awardees; see www.scienceofsciencepolicy.net/scisipmembers.aspx.

7. See Marburger, Chap. 2, in this book.