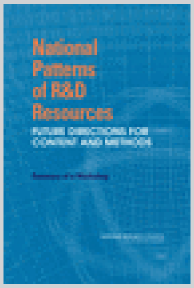


National Patterns of R&D Resources: Future Directions for Content and Methods: Summary of a Workshop

ISBN
978-0-309-28325-0

107 pages
6 x 9
PAPERBACK (2013)

Michael L. Cohen and Esha Sinha, Rapporteurs; Committee on National Statistics; Division on Behavioral and Social Sciences and Education; National Research Council

National Patterns of R&D Resources

FUTURE DIRECTIONS FOR CONTENT AND METHODS

Summary of a Workshop

Michael L. Cohen and Esha Sinha, *Rapporteurs*

Committee on National Statistics

Division of Behavioral and Social Sciences and Education

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS **500 Fifth Street, NW** **Washington, DC 20001**

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This study was supported by Contract/Grant No. SES-1024012 between the National Academy of Sciences and the National Science Foundation. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number-13: 978-0-309-28325-0
International Standard Book Number-10: 0-309-28325-6

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, NW, Keck 360, Washington, DC 20001; (800) 624-6242 or (202) 334-3313; http://www.nap.edu.

Printed in the United States of America

Suggested citation: National Research Council. (2013). *National Patterns of R&D Resources: Future Directions for Content and Methods: Summary of a Workshop.* Michael L. Cohen and Esha Sinha, rapporteurs. Committee on National Statistics, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. C. D. Mote, Jr., is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. C. D. Mote, Jr., are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

STEERING COMMITTEE FOR THE WORKSHOP ON FUTURE DIRECTIONS FOR THE NSF *NATIONAL PATTERNS OF RESEARCH AND DEVELOPMENT* REPORTS

Karen Kafadar (*Chair*), Department of Statistics, Indiana University
William B. Bonvillian, Director, Washington, DC, Office, Massachusetts Institute of Technology
Fernando Galindo-Rueda, Directorate for Science, Technology, and Industry, OECD
Christopher T. Hill, School of Public Policy, George Mason University
Joel L. Horowitz, Department of Economics, Northwestern University
David Newman, Department of Computer Science, University of California, Irvine
Stephanie S. Shipp, Science and Technology Policy Institute, Institute for Defense Analysis, Washington, DC
Eric V. Slud, Center for Statistical Research and Methodology, U.S. Census Bureau
Howard Wainer, National Board of Medical Examiners, Philadelphia, PA

Michael L. Cohen, *Senior Program Officer*
Esha Sinha, *Associate Program Officer*
Agnes Gaskin, *Senior Project Assistant*

COMMITTEE ON NATIONAL STATISTICS 2012-2013

Lawrence D. Brown (*Chair*), Department of Statistics, The Wharton School, University of Pennsylvania
John M. Abowd, School of Industrial and Labor Relations, Cornell University
David Card, Department of Economics, University of California, Berkeley
Alicia Carriquiry, Department of Statistics, Iowa State University
Constantine Gatsonis, Center for Statistical Sciences, Brown University
James S. House, Survey Research Center, Institute for Social Research, University of Michigan
Michael Hout, Survey Research Center, University of California, Berkeley
Sallie Keller, Provost, University of Waterloo, Ontario, Canada
Lisa Lynch, Heller School for Social Policy Management, Brandeis University
Sally C. Morton, Biostatistics Department, Graduate School of Public Health, University of Pittsburgh
Ruth Peterson, Criminal Justice Research Center, Ohio State University
Edward H. Shortliffe, Biomedical Informatics, Columbia University and Arizona State University
Hal Stern, Ted and Janice Smith Family Foundation, Donald Bren School of Information and Computer Sciences, University of California, Irvine
John Thompson, NORC at the University of Chicago
Roger Tourangeau, Westat, Rockville, MD

Constance F. Citro, *Director*

Acknowledgments

I would like to express my indebtedness to a number of individuals that have provided assistance in producing this report. At the National Center for Science and Engineering Statistics (NCSES) at the National Science Foundation (NSF), I would first like to thank Lynda Carlson for initiating this project. I am also very thankful to Tom Plewes of the Committee on National Statistics (CNSTAT) at the National Research Council (NRC), who served as the initial study director and, with Lynda Carlson, who laid out the major topics to be addressed.

Next, I am very pleased to be able to thank the members of the Steering Committee on Future Directions for the NSF *National Patterns of Research and Development* Reports, who provided their input and expertise to make this workshop a success. They expended a great deal of time and energy on behalf of this project and were extremely willing to hear other perspectives on the issues involved. I extend particular thanks to Fernando Galindi-Rueda, a steering committee member, who also provided an excellent presentation at the workshop. It was a pleasure collaborating with all of them.

I am also very indebted to John Jankowski and Mark Boroush of NCSES, who were extremely generous with their time and expertise, always willing to help with various requests, such as reviewing preliminary agendas, participating in conference calls with presenters, and setting up and joining in on meetings with staff and with presenters. In addition, they both provided excellent presentations at our kick-off meeting to plan the workshop and at the workshop itself. I am also indebted to several other members of the NCSES staff, especially Ray Wolf and Jock Black for their time and input at staff meetings.

As is the case with all workshops, the presentations are key. We were very fortunate to hear from a wide range of experts in various aspects of research and development statistics: see the agenda (in addition to the previously mentioned Mark Boroush, Fernando Galindo-Rueda and John Jankowski): Jeff Alexander, Daniel Carr, Julie Gershunskaya, David Goldston, Martin Grueber, Kaye Husbands-Fealing, John King, Kei Koizumi, Charles Larson, and David Mowery. We are particularly indebted to Daniel Carr, who served as a consultant to the study, and Julie Gershunskaya, who provided presentations on data display and small-area estimation, respectively, which were targeted for application with NCSES data. I would also like to Linda Yu and her colleagues at Synthosys for providing insight into STAR METRICS.

I also would like to give my sincere appreciation to the work of other CNSTAT staff. I and my fellow steering committee members are indebted to Michael Cohen and Esha Sinha, who ably supported our work and served as the rapporteurs for this volume. In addition, I am especially thankful for the personal participation of Constance F. Citro, CNSTAT director, who helped both in the initial structure of the project and at every step along the way to conclusion. I also thank Agnes Gaskin who performed her usual exemplary service on all administrative matters, including travel, meetings, and final report preparation.

This workshop summary has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the NRC. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for quality and objectivity. The review comments and draft manuscript remain confidential to protect the integrity of the process. We thank the following individuals for their review of this report: John F. Geweke, Centre for the Study of Choice, University of Technology, Sydney, Australia; Martin Grueber, Technology Partnership Practice, Battelle, Cleveland, Ohio; John King, Agricultural Economics and Rural Development, USDA Office of the Chief Scientist; Charles F. Larson, Industrial Research Institute, Washington, DC; J. David Roessner, Center for Science, Technology, and Economic Development, SRI International; and Alyson G. Wilson, research staff, IDA Science and Technology Policy Institute, Washington, DC.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the content of the report nor did they see the final draft of the report before its release. The review of this report was overseen by Alicia Carriquiry, Department of Statistics, Iowa State University. Appointed by the NRC, she was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authors.

Finally, I recognize the many federal agencies that support CNSTAT directly and through a grant from the NSF. Without their support and their commitment to improving the national statistical system, the committee work that is the basis of this report would not have been possible.

Karen Kafadar, *Chair*
Steering Committee for the Workshop on
Future Directions for the NSF *National*
Patterns of Research and Development Reports

Contents

1

Introduction

The National Center for Science and Engineering Statistics (NCSES) of the National Science Foundation (NSF) is involved in the collection, analysis, and dissemination of data on science and engineering. NCSES conducts a number of surveys covering various aspects of this topic area, and the agency produces 30 reports a year, including the *National Patterns of R&D Resources* (hereafter referred to as *National Patterns*). Based primarily on input from five major NCSES research and development (R&D) surveys, this annual publication provides an overview of a calendar year's distribution of R&D funds broken out by (1) the type of research carried out—basic, applied, or development; (2) the type of provider; and (3) the type of recipient. The publication consists of tabular representations of R&D expenditure and funding time series. It also provides some subnational geographic detail. Tables of the amounts and associated time plots facilitate comparison of the funding and expenditure patterns both over time and with selected countries.

Looking forward, NCSES is interested in retaining or enhancing the future relevance of *National Patterns*. Changes and enhancement might include

- changing the main tabular presentations currently used;
- changing which of the current portfolio of variables collected on the five major input surveys are tabulated;
- adding new variables on the questionnaires for these surveys;
- making use of administrative records sources of data; and

BOX 1-1
Statement of Task

An ad hoc committee will plan and organize commissioned papers for, and conduct a public workshop to review and consider, future directions for the National Patterns of Research and Development Program of the National Center for Science and Engineering Statistics of the National Science Foundation. The workshop sessions will feature invited presentations and discussions on such issues as:

- the responsiveness of the information content to users' needs;
- targets for expanded content;
- the usefulness of adjustments for consistency;
- timeliness vs. data quality;
- the appropriateness of the methods for estimated values (e.g., estimation of R&D performance by nonprofit organizations, business R&D expenditures, and federal and state intramural R&D expenditures);
- consistency of indicators from other sources (e.g., Bureau of Economic Analysis, OECD);
- international comparability; and
- categorization of R&D by socioeconomic objective and science/engineering field.

The committee will develop the workshop agenda, commissioned papers, select and invite speakers and discussants, and moderate the discussion.

- adding new tabulations, statistics, or graphics that include information from new sources.

This enhancing of *National Patterns* could also involve improvement of the statistical methods used to create these products and thereby improve the quality of the statistical products in *National Patterns*.

The charge to the Committee on National Statistics (CNSTAT) of the National Research Council (NRC) was to organize a workshop to examine whether and how these various dimensions of *National Patterns* could be improved: see Box 1-1. To address the charge, CNSTAT formed the Steering Committee on Future Directions for the NSF *National Patterns of Research and Development* Reports.

BACKGROUND

Statistics on R&D are important indicators of innovation, the transfer of ideas and knowledge, which in turn are key drivers of economic growth (see, e.g., Romer, 1986, 1990), and R&D expenditures are one indicator of the generation and diffusion of knowledge (see Rosenberg, 1994). A key aspect of the role of R&D in the process of economic growth is that it generates spillover benefits. Given the contribution of R&D to economic growth and, consequently, its role in policy decisions, NSF began to measure it in the 1950s.

Although the idea of measuring R&D seems straightforward, there are complexities to carrying it out. As pointed out by Jaffe and Trajtenberg (2005), knowledge, innovation, and technical change are elusive notions. They are hard to define and harder to measure. To its credit, for more than 60 years NCSES (and its predecessors) has collected and produced consistent statistical tables and graphs on domestic R&D expenditures, producing the statistics in a timely fashion. Underlying the publication process are the efforts undertaken by the agency to overcome the complexities of definitions and various efforts to address issues such as missing data and international comparability.

National Patterns of R&D Resources is a compendium of five annual surveys. Each publication in the series integrates and synthesizes the data from these periodic surveys of R&D expenditures by U.S. R&D performers in order to analyze current patterns of R&D activity in the United States in relation to the historical record and to the reported R&D levels of other industrialized countries. The goal of this effort is to aid NCSES in fulfilling the legislative mandate of the NSF: see Box 1-2.

BOX 1-2
The National Science Foundation Act of 1950

The National Science Foundation was created in 1950 with a mission "to promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense." That 1950 act that created the agency also made it a statistical agency. In that vein, it is also charged with providing "a central clearinghouse for the collection, interpretation, and analysis of data on scientific and engineering resources, and to provide a source of information for policy formulation by other agencies of the Federal government."

THE WORKSHOP AND THIS REPORT

The steering committee identified seven topics for presentations and subsequent discussions at the workshop:

1. the purposes and uses of *National Patterns*;
2. advances in international comparability of the statistical outputs in *National Patterns*;
3. the nature and estimation of R&D expenditure data for nonprofit organizations;
4. the benefits of collecting and reporting on additional variables relevant to R&D funds;
5. improving communication in *National Patterns*;
6. potential methodological uses of administrative records for R&D estimation; and
7. the use of small-area estimation techniques for estimating R&D amounts for small domains such as states crossed with industrial categories.

The reader should note that the agenda items are in accord with the issues mentioned in the above statement of task. A workshop is not a consensus activity, and so no recommendations or other consensus findings are offered in this report.

The purpose of the workshop and this summary are to explore a set of possible next steps for improving the relevance, the content, and the presentation of *National Patterns* reports by better understanding the demands of users, the constraints of the data producers, the techniques used to address data limitations, the purpose of the current strategies for data dissemination, and the challenges in using administrative data. The workshop provided a variety of views and suggested a range of possibilities for improvements to the sponsoring agency. The workshop agenda is presented in Appendix B. The workshop presentations are available on CNSTAT's webpage: http://sites.nationalacademies.org/dbasse/cnstat/dbasse_070728 [June 2013].

This report generally follows the workshop structure, summarizing the presentations and the discussions on each topic. Chapter 2 covers the historical background of *National Patterns*, including a description of the surveys that feed into the report, the variables collected on those surveys and tabulated in *National Patterns*, and other NSF publications that make use of the R&D data. This presentation also mentions comparable publications from international agencies or organizations. Chapter 3 addresses the user perspective, domestically and internationally: namely, what modifications could be made to *National Patterns* that could address currently unmet or anticipated future user needs. Chapter 4 highlights the missing gaps in the data that are currently collected by NCSES and points out areas in which techniques or new data sources might be used to improve current estimates. Chapter 5 looks at a key methodological issue of how to produce R&D statistics for small domains. Finally, Chapter 6 concerns how to present or display the information in *National Patterns* data so that readers can recognize the patterns more easily.

We stress that this summary is limited to the views expressed either during the activities undertaken in planning the workshop or at the workshop itself. Therefore, all views expressed are those of the workshop presenters or other workshop attendees.

2

What Is *National Patterns*?

NATIONAL PATTERNS OF R&D RESOURCES: KEY ASPECTS OF DATA, METHODS, AND REPORTS

Mark Boroush from the National Science Foundation (NSF) laid the groundwork for the workshop by describing the series of publications *National Patterns*, including the sources of data that are used as inputs, the statistical methods used to address data limitations, the tabulations and other statistical products that appear in the publication, and related reports.

Boroush began by noting NSF's commitment toward producing quality statistics on R&D expenditure patterns. He noted that the National Center for Science and Engineering Statistics (NCSES), the NSF unit with primary responsibility for *National Patterns,* is determined to maintain the quality of the tabulations and other statistical products and to maintain their policy relevance as well. Boroush said that this is an important workshop for NCSES: he and his colleagues hope that a number of ideas will surface that will help them keep these commitments for quality and relevance in the face of both current and future challenges.

National Patterns of R&D Resources reports annual U.S. total R&D expenditures in a performer-funder matrix that is broken out by type of research—basic, applied, or development: see Tables 2-1 and 2-2. Many elements of the performer-funder matrix have been relatively stable since 1953, which supports analysis of trends over time.

National Patterns is a derived product: it is a compendium that draws from five annual NSF surveys on R&D expenditures and awards. Currently, the primary publications associated with *National Patterns* are *Info Briefs* and *Data Updates*. *Info Brief* is a short publication (generally 10-15 pages) that contains recent data, graphical analysis, and primary conclusions. The primary purpose of *Info Brief* is to give a glimpse of the United States' R&D performance in the absence of a full *National Patterns* report. The annual *National Patterns* report is given the subtitle of *Data Update,* as the report provides an annual update of R&D expenditure and funding series.[1] The latest *Data Update* that is available from NCSES is for 2009. Boroush added that the 2010 and 2011 *Data Updates* will be available in the winter of 2012.[2]

As noted above, R&D statistics in *National Patterns* are disaggregated by category of R&D performer, category of source of funding, character of work (basic research, applied research, and development), and sometimes state of provider or state of recipient. The funds are also reported both in current and in constant dollars. Along with producing U.S. domestic R&D expenditure and funding statistics, NCSES since 1981 has also published the ratio of R&D funding to the gross domestic product (GDP). For comparative purposes, NCSES also publishes the total R&D expenditures of other large countries.

Boroush displayed recent examples of these various statistical products depicting trends in federal and nonfederal R&D expenditure, the ratio of R&D expenditure to GDP for selected nations, and the share of performing sector and funding source in total R&D expenditures for 2009: see Figures 2-1 and 2-2, also see Table 2-3. The most important outputs of *National Patterns* show the trend of U.S. R&D expenditure for the last 60 years, indicating how the shares of various performing sectors and funding sources have changed and comparing U.S. R&D funding with that of other countries. Another very important statistical product, Boroush said, is the amount of R&D expenditure in individual states.

Boroush said that efforts had been made to acquire an understanding of the *National Patterns* user community, which includes federal policy makers, various federal agencies, and congressional staff. There is also substantial international interest in U.S. R&D expenditure and funding statistics from statistical agencies in other countries and from the OECD, the European Union (EU), and representative organizations, such as the United Nations Educational, Scientific and Cultural Organization (UNESCO). In addition, Boroush said that both domestic and international media, including the business press, and the broader science and technology community

---

[1] *Info Briefs* and full *National Patterns* reports are available at http://www.nsf.gov/statistics/natlpatterns [February 2013].

[2] The 2010 and 2011 *Data Updates* were published several months after the workshop: see National Science Foundation (2013).

TABLE 2-1 All U.S. R&D Expenditures, by Performing Sector and Source of Funds: 1996-2009

	All Performers	Federal	Industry			Industry FFRDCs	U&C	
Year	All Sources	Federal	Total	Federal	Industry	Total	Total	Federal
1996	197,346	16,585	142,371	21,356	121,015	2,297	23,718	14,084
1997	212,152	16,819	155,409	21,798	133,611	2,130	24,884	14,530
1998	226,457	17,362	167,102	22,086	145,016	2,078	26,181	15,174
1999	245,007	17,851	182,090	20,496	161,594	2,039	28,176	16,264
2000	267,983	18,374	199,961	17,117	182,844	2,001	30,705	17,727
2001	279,755	22,374	202,017	16,899	185,118	2,020	33,743	19,784
2002	278,744	23,798	193,868	16,401	177,467	2,263	37,215	22,395
2003	291,239	24,982	200,724	17,798	182,926	2,458	40,484	25,129
2004	302,503	24,898	208,301	20,266	188,035	2,485	43,122	27,168
2005	324,993	26,322	226,159	21,909	204,250	2,601	45,190	28,254
2006	350,162	28,240	247,669	24,304	223,365	3,122	46,955	28,810
2007	376,960	29,859	269,267	26,585	242,682	5,165	49,010	29,351
2008	403,040	29,839	290,681	36,360	254,321	6,346	51,650	30,341
2009	400,458	30,901	282,393	39,573	242,820	6,446	54,382	31,575

NOTE: FFRDCs = federally funded research and development centers, U&C = universities and colleges.
SOURCE: National Science Foundation (2012c, Table 2).

TABLE 2-2 U.S. Basic Research Expenditures, by Performing Sector and Source of Funds: 1996-2009

	All Performers	Federal	Industry				U&C	
Year	All Sources	Federal	Total	Federal	Industry	Total	Total	Federal
1996	32,799	2,680	7,498	650	6,848	708	16,042	10,092
1997	36,921	2,746	9,795	1,029	8,766	625	17,654	10,924
1998	35,372	3,003	5,853	1,002	4,851	568	19,365	11,941
1999	38,935	3,347	6,645	1,108	5,537	557	21,022	12,892
2000	42,759	3,765	7,040	925	6,115	547	22,917	13,966
2001	47,751	4,260	8,053	754	7,299	552	25,240	15,553
2002	51,383	4,511	7,547	888	6,659	534	27,970	17,724
2003	54,611	4,664	8,330	1,386	6,944	299	30,023	19,658
2004	56,092	4,697	7,835	1,072	6,763	175	31,989	21,150
2005	59,686	4,770	8,667	1,108	7,559	136	34,028	22,186
2006	61,199	4,716	8,384	1,444	6,940	652	35,635	22,690
2007	66,206	4,621	11,268	2,780	8,488	2,258	37,271	23,043
2008	70,220	4,957	12,368	1,475	10,893	2,423	38,840	23,500
2009	75,969	5,507	14,784	1,340	13,444	2,550	40,543	24,242

NOTE: FFRDCs = federally funded research and development centers, U&C = universities and colleges.
SOURCE: National Science Foundation (2012c, Table 3).

				U&C FFRDCs	Other Nonprofit				Nonprofit FFRDCs
Other Gov't.	Industry	U&C	Other Non-profit	Total	Total	Federal	Industry	Other Non-profit	Total
1,861	1,672	4,436	1,666	5,395	6,209	2,906	730	2,574	772
1,922	1,808	4,838	1,786	5,463	6,626	3,014	809	2,804	821
1,972	1,950	5,163	1,922	5,559	7,332	3,281	859	3,192	843
2,098	2,082	5,619	2,112	5,652	8,207	3,761	931	3,516	993
2,247	2,174	6,232	2,326	5,742	9,734	4,510	1,020	4,204	1,465
2,397	2,190	6,827	2,546	6,225	11,182	5,488	1,029	4,666	2,192
2,557	2,160	7,344	2,758	7,102	12,179	5,778	998	5,404	2,319
2,742	2,129	7,650	2,833	7,301	12,796	5,945	1,020	5,831	2,494
2,883	2,190	7,936	2,945	7,659	13,394	6,537	1,041	5,816	2,644
2,922	2,323	8,578	3,113	7,817	14,077	6,545	1,107	6,425	2,828
3,021	2,509	9,285	3,329	7,306	13,928	6,044	1,182	6,702	2,943
3,265	2,741	9,959	3,694	5,567	14,777	5,980	1,257	7,541	3,316
3,518	3,004	10,707	4,080	4,766	16,035	6,236	1,301	8,498	3,724
3,675	3,279	11,436	4,418	4,968	17,531	7,133	1,258	9,141	3,835

				U&C FRDCs	Other Nonprofit				Nonprofit FFRDCs
Other Gov't.	Industry	U&C	Other Non-profit	Total	Total	Federal	Industry	Other Non-profit	Total
1,149	1,032	2,740	1,028	2,606	3,187	1,248	428	1,510	79
1,248	1,175	3,144	1,162	2,671	3,322	1,317	449	1,557	108
1,330	1,315	3,483	1,296	2,660	3,710	1,461	477	1,773	213
1,432	1,421	3,835	1,442	2,765	4,203	1,734	517	1,952	397
1,550	1,499	4,298	1,604	2,874	5,000	2,099	566	2,334	616
1,663	1,519	4,737	1,767	3,104	5,626	2,464	571	2,590	915
1,768	1,494	5,077	1,907	3,714	6,129	2,575	554	3,000	979
1,850	1,438	5,165	1,913	3,747	6,519	2,714	567	3,238	1,029
1,958	1,488	5,392	2,001	3,730	6,596	2,788	578	3,229	1,070
2,042	1,624	5,999	2,177	3,820	7,084	2,903	614	3,568	1,181
2,155	1,791	6,624	2,376	3,344	7,227	2,849	656	3,721	1,242
2,363	1,983	7,207	2,674	1,724	7,714	2,829	698	4,187	1,350
2,533	2,162	7,708	2,937	1,672	8,514	3,073	722	4,719	1,447
2,627	2,344	8,173	3,158	1,808	9,270	3,496	698	5,075	1,508

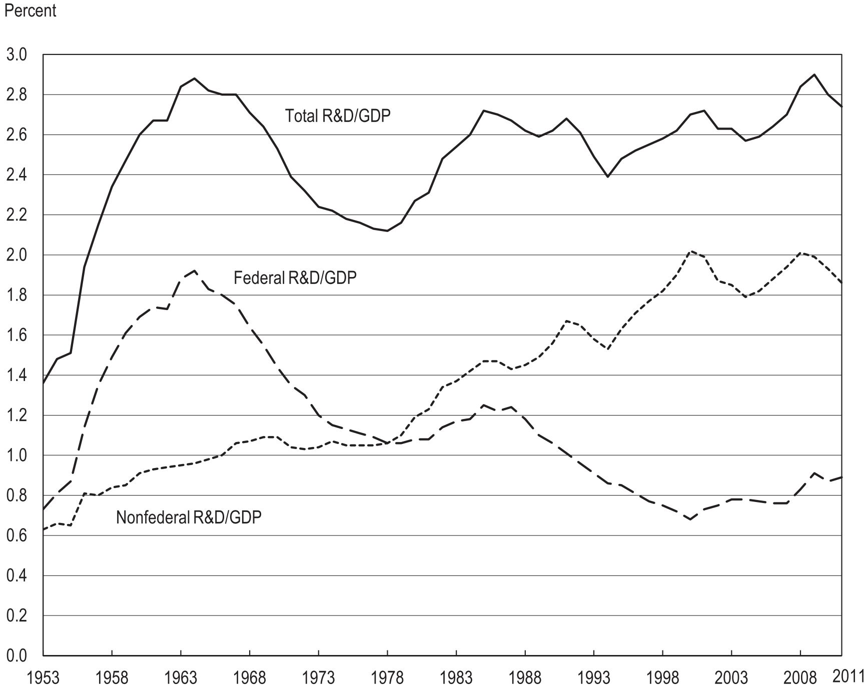


FIGURE 2-1 Ratio of U.S. R&D to gross domestic product (GDP), roles of federal and nonfederal funding for R&D, 1953-2011.
SOURCE: National Science Foundation (2013, Figure 4).

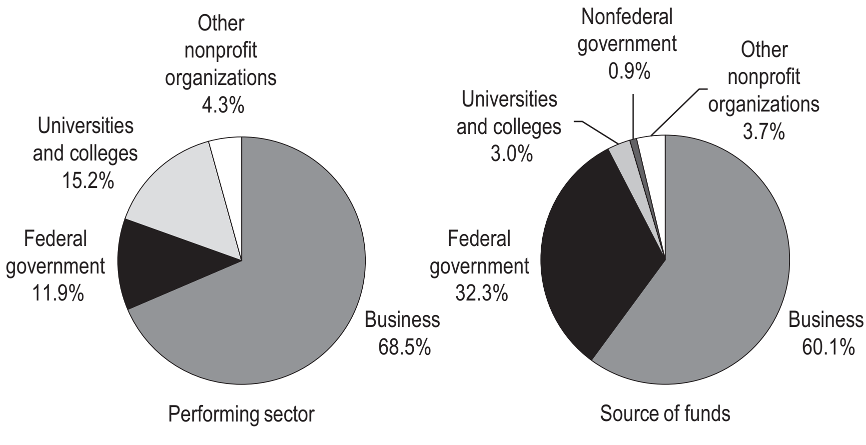


FIGURE 2-2 Share of U.S. R&D expenditures by performing sector and by funding sector, 2011.
SOURCE: National Science Foundation (2013, Figure 2).

TABLE 2-3 International Comparisons of Gross Domestic Expenditures on R&D and R&D Share of Gross Domestic Product, by Selected Country/Economy: 2009 (or most recent year)

Region/Country-Economy	GERD (PPP $millions)	GERD/GDP (%)
North America		
United States	401,576.5	2.88
Canada	24,551.3	1.92
Mexico (2007)	5,719.6	0.37
South America		
Brazil (2008)	21,649.4	1.08
Argentina (2007)	2,678.8	0.51
Chile (2004)	1,227.7	0.68
Europe		
Germany	82,730.7	2.78
France	47,953.5	2.21
United Kingdom	40,279.5	1.85
Italy	24,752.6	1.27
Spain	20,496.4	1.38
Sweden	12,494.9	3.62
Netherlands	12,273.8	1.82
Switzerland (2008)	10,512.7	3.00
Austria	8,931.3	2.75
Belgium	7,684.9	1.96
Finland	7,457.8	3.96
Denmark	6,283.8	3.02
Poland	4,874.9	0.68
Norway	4,734.1	1.76
Portugal	4,411.0	1.66
Czech Republic	4,094.8	1.53
Ireland	3,164.6	1.79
Ukraine	2,485.7	0.86
Hungary	2,333.8	1.15
Greece (2007)	1,867.9	0.59
Romania	1,471.5	0.47
Slovenia	1,043.6	1.86
Belarus	813.3	0.65
Croatia	743.1	0.84
Luxembourg	708.5	1.68
Slovak Republic	595.5	0.48
Middle East		
Israel	8,810.1	4.28
Turkey	8,681.2	0.85
Iran (2008)	6,465.2	0.79

continued

TABLE 2-3 Continued

Region/Country-Economy	GERD (PPP $millions)	GERD/GDP (%)
Africa		
South Africa (2008)	4,689.3	0.93
Tunisia	1,048.5	1.21
Egypt	997.3	0.21
Morocco (2006)	765.1	0.64
Central Asia		
Russian Federation	33,368.1	1.24
South Asia		
India (2007)	24,439.4	0.76
Pakistan	2,055.2	0.46
East, Southeast Asia		
China	154,147.4	1.70
Japan	137,908.6	3.33
South Korea (2008)	43,906.4	3.36
Taiwan	21,571.8	2.93
Singapore	5,626.5	2.35
Malaysia (2006)	2,090.9	0.64
Thailand (2007)	1,120.8	0.21
Australia, Oceania		
Australia (2008)	18,755.0	2.21
New Zealand (2007)	1,422.5	1.17
Selected country groups		
G-20 countries	1,181,263.7	2.01
OECD (2008)	965,629.1	2.33
EU-27	297,889.6	1.90

NOTE: NOTE: EU-27 = European Union 27 member states, G-20 = group of finance ministers and central bank governors from 20 major economies, GDP = gross domestic product, GERD = gross domestic expenditures on R&D, OECD = Organisation for Economic Co-operation and Development, PPP = purchasing power parity.

are interested in obtaining a better understanding of how well the support for science is faring from year to year, Boroush said.[3]

[3]The January 2013 *Info Brief* had 182 views, and the 2009 *Data Update* had 255 views as of February 26, 2013 (personal communication, Mark Boroush, NCSES).

INPUTS AND TIMELINESS

There are five active censuses and surveys used as inputs for *National Patterns*:

- Business R&D and Innovation Survey (BRDIS): BRDIS is the current business sector survey, which replaced the Survey of Industrial R&D (SIRD) starting from 2008. In moving to BRDIS, the questionnaire was substantially revised and lengthened to include a larger set of questions, such as R&D performed abroad by companies that are based in the United States.
- Survey of Federal Funds for Research and Development (known as the Federal Funds Survey): Federal Funds Survey is a census that collects data on federal support of national scientific activities in terms of budget obligations and outlays. The survey is completed by 15 federal departments and their 72 subagencies and by 12 independent agencies.
- Federally Funded Research and Development Centers (FFRDCs) R&D Survey: This annual census collects information on R&D expenditures of FFRDCs by source of funds. It was conducted for all university-administered FFRDCs until 2000. Subsequently, the survey population was expanded to include all FFRDCs. In 2010, the questionnaire was expanded to gather information on the total operating budgets of FFRDCs, on R&D expenditures from the American Recovery Reinvestment Act of 2009, and by type of costs.
- Higher Education Research and Development Survey (HERD): The recently revised version of the previous Survey of Research and Development Expenditures at Universities and Colleges is a census of all R&D spending at colleges and universities. HERD serves as the primary source of information on R&D expenditures in academia in the United States. One of the modifications in the transfer to HERD was the decision to include information on nonscience and nonengineering R&D.
- Survey of State Agency Research and Development Expenditures: Formerly known as the Survey of State Government Research and Development Expenditures, the purpose of the survey is to capture R&D activity performed and funded by the nation's 50 states, the District of Columbia, and Puerto Rico ("state profiles").

In addition, there is information from a survey that was conducted three times:

- Survey of Research and Development Funding and Performance by Nonprofit Organizations: This survey was conducted in 1973, 1996, and 1997. The nonprofit data in *National Patterns* reports are either taken from the Federal Funds Survey or are estimates derived from the data collected in 1996 and 1997.[4]

Since *National Patterns* draws from these five active surveys, and given that they have different timelines for data collection, processing and dissemination, the timely publication of *National Patterns* depends on the smooth running of the associated survey cycles. To produce *National Patterns* for year *t*, NCSES has to wait different amounts of time, depending on the census or survey, before it can do the editing, imputation, and other data processing activities necessary in order to produce the official estimates: see Figure 2-3. Since the data collection cycles of the five input censuses and surveys are not the same, the time gaps between the data collection and the official estimates will be different for different data. Boroush noted, however, that NCSES also releases data products for each of the individual surveys, which are often more timely. For example, as of the date of the workshop, September 6, 2012, information on R&D performed by federally funded R&D centers was available for 2011, while the latest data update for *National Patterns* was for 2009.

Boroush then explored the reason behind the delays in release of *National Patterns*. The current 3-year delay primarily stems from the timing of BRDIS. As can be seen in Figure 2-3, business R&D data for 2010 were not available until 2012 due both to the cycle of data collection and data processing. This hampers NCSES's ability to produce more timely results. Given this 2-year lag in producing business R&D data, NCSES has considered using the information available from the "projected R&D for next year" item on the BRDIS questionnaire: see Figure 2-4. The original intent of this survey item was to gain an understanding of the plans of companies for R&D outlays the following year. In a comparison of the projected R&D numbers from 2008 and 2009 surveys and the actual R&D performed by the companies the following year, NCSES staff found that the numbers that companies reported in the "look ahead" questions are reasonable proxies for the actual R&D performed. NCSES believes that if necessary it could use these numbers to provide estimated BRDIS numbers that could support

---

[4]NCSES releases tables and InfoBriefs drawing on data collected from the component surveys that feed into *National Patterns*:

- BRDIS, see http://www.nsf.gov/statistics/industry [February 2013].
- Federal Funds, see http://www.nsf.gov/statistics/fedfunds [February 2013].
- R&D Expenditure at FFRDCs, see http://www.nsf.gov/statistics/ffrdc [February 2013].
- HERD, see http://www.nsf.gov/statistics/herd [February 2013].
- Science and Engineering State Profiles, see http://www.nsf.gov/statistics/pubseri.cfm?seri_id=18 [February 2013].

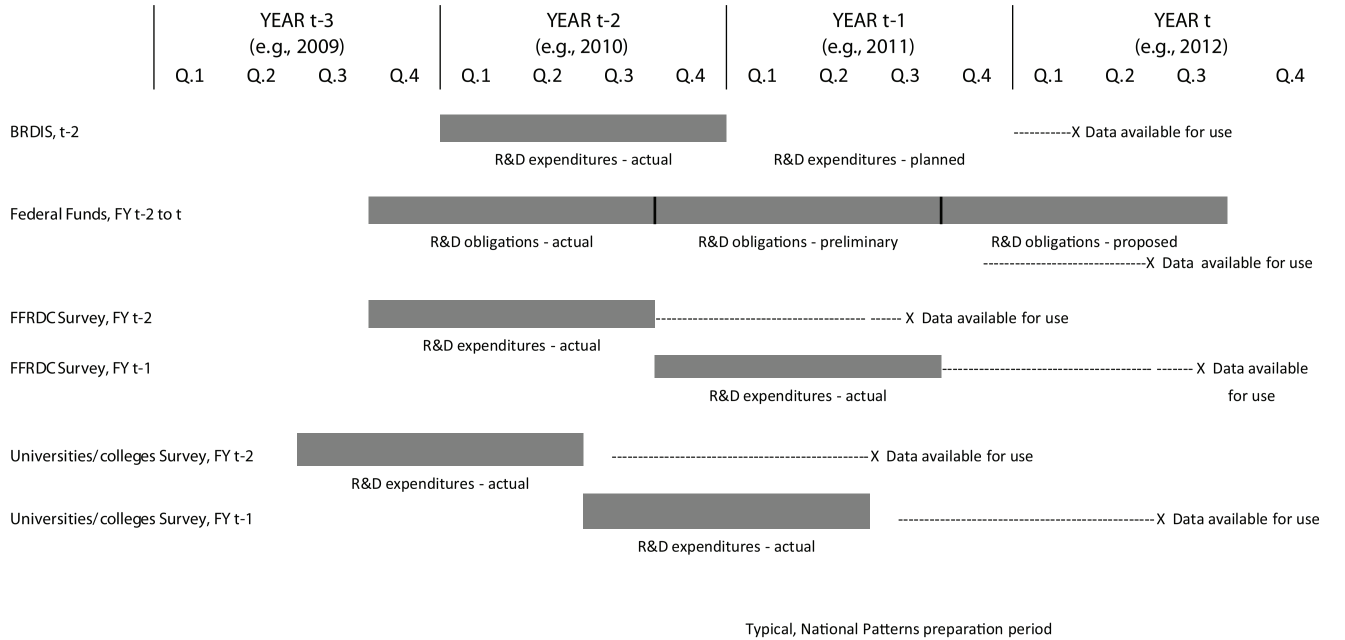
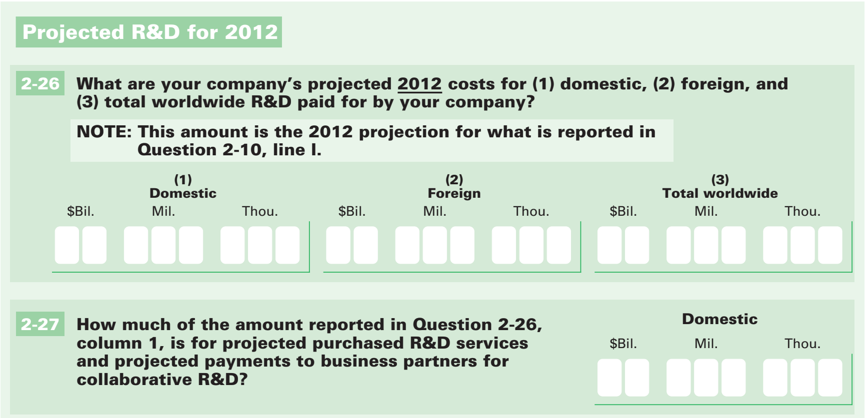


FIGURE 2-3 Timing of four surveys that are inputs to *National Patterns*.
NOTE: BRDIS = Business R&D and Innovation Survey, FFRDC = federally funded research and development centers.
SOURCE: Boroush (2012).


Projected R&D for 2012

2-26 **What are your company's projected 2012 costs for (1) domestic, (2) foreign, and (3) total worldwide R&D paid for by your company?**

NOTE: This amount is the 2012 projection for what is reported in Question 2-10, line l.

(1) Domestic			(2) Foreign			(3) Total worldwide		
$Bil.	Mil.	Thou.	$Bil.	Mil.	Thou.	$Bil.	Mil.	Thou.

2-27 **How much of the amount reported in Question 2-26, column 1, is for projected purchased R&D services and projected payments to business partners for collaborative R&D?**

Domestic		
$Bil.	Mil.	Thou.

FIGURE 2-4 Survey item from BRDIS 2011 questionnaire.
SOURCE: National Science Foundation (2012a).

publication of *National Patterns* a year earlier.[5] However, Boroush noted that NCSES has not yet made the decision to do so given that this relationship has not been established stably over time and that other approaches to the timeliness problem may be proposed. Very recently, the data processing for BRDIS has been expedited, and the time lag for *National Patterns* is now less than 1 year. As the only federal statistical agency producing estimates of national- and state-level R&D funding levels, NCSES has always strived to produce a consistent R&D time series to meet the plethora of demands of a varied set of users, and that consistency has been highly valued by users.

NEXT STEPS

Boroush said that although NCSES has strived to use statistical methods reflective of best practices in producing *National Patterns*, methodological improvements may be possible. He cited the issues in the statement of task for the workshop and expanded on some of them. First is the content and format of the *National Patterns* reports. He said he wanted the workshop participants to examine how the agency could pursue different routes of presenting the information published in *National Patterns*. Second, he noted the data gap due to the absence of a survey on nonprofit organizations. A

[5]Respondent companies are likely to have a reasonable sense of "next year's R&D" as BRDIS is fielded in the second quarter of "next year." For example, companies will report their 2012 R&D expenditure in 2013 and therefore have a good estimate of their 2013 R&D expenditure.

portion of R&D expenditures to nonprofit organizations and funding by nonprofit organizations comes from the Federal Funds Survey. The main omission is the estimate of the amount of R&D funding from nonprofit organizations to other nonprofit organizations. Boroush said that NCSES generally agrees that there is a need for an updated R&D survey on nonprofit organizations, but that it has been unable to undertake such a survey due to staff and budget constraints. Boroush said he hoped that workshop participants would provide ideas for a new nonprofit survey to contribute to the *National Patterns* aggregate R&D estimates or suggest approaches to estimating R&D undertaken by nonprofits through other means.[6]

Boroush also discussed the possibility of collecting new variables on the current censuses and surveys, including state intramural R&D expenditures, and the categorization of R&D by socioeconomic objectives and science and engineering fields. Standards for collecting data on socioeconomic objectives were introduced in the third edition of the *Frascati Manual*[7] (see Godin, 2008), in which greater stress was placed on "functional" classifications, notably the distribution of R&D by "objectives." Boroush pointed out that BRDIS does intermittently survey companies to report their R&D performance for defense purposes and for environmental protection applications, even though the latter category is not fully Frascati-compliant: see Box 2-1. NCSES also publishes academic expenditures by science and engineering subfields through NSF's online communal tool WebCASPAR.[8] The original targets for categorization of R&D expenditure by socioeconomic objectives and fields of science were government budget appropriations (GBAORD) and academic R&D (HERD) respectively. Revisions in the *Frascati Manual* have expanded the scope of categorization to include all kinds of R&D expenditures. Boroush asked participants what priorities should be given to solving the various methodological issues that arise in trying to address this data gap.

In conclusion, Boroush reiterated the utility of *National Patterns* and the past, current, and future efforts undertaken by NCSES to make the publication better in terms of introducing new concepts, improving estimation methods, and revamping the underlying surveys.

---

[6]The nonprofit survey issue is addressed in greater detail in Chapter 4.

[7]The *Frascati Manual* details an internationally recognized methodology for collecting and compiling R&D statistics and has become an essential tool for statisticians working on R&D surveys. The manual was originally written by and for the experts in OECD member countries. It is now a standard for conducting R&D surveys in nonmember countries, as a result of its adoption in technology surveys of the UNESCO Institute for Statistics. For further information, see http://www.oecd.org/innovation/inno/frascatimanualproposedstandardpracticeforsurveysonresearchandexperimentaldevelopment6thedition.htm [February 2013].

[8]WebCASPAR is the Integrated Science and Engineering Resources Data System; see https://webcaspar.nsf.gov [January 2013].

BOX 2-1
Collecting R&D Data for Priorities

The *Frascati Manual* recommends collecting performer-reported data in all sectors for two priorities: (1) defense and (2) control and care of the environment. The manual also recommends that the major fields of science and technology should be adopted as the functional fields of a science classification system. This classification should be used for the R&D expenditure of the government, higher education and private nonprofit sectors, and if possible, the business enterprise sector, and personnel data in all sectors.

ADJUSTMENTS AND CATEGORIES: DISCUSSION

Karen Kafader commended Mark Boroush on his presentation and opened the floor to discussion. Christopher Hill wanted to know whether adjustments made in the estimates produced by the individual R&D surveys are carried forward in the *National Patterns* publication. Boroush answered that whenever any revisions are made in the survey estimates or in the external sources of information, they are also included in the data updates for *National Patterns*. For example, he said, any revisions in the GDP numbers from the Bureau of Economic Analysis change the ratios of R&D to GDP in *National Patterns*.

Also, Boroush said, NCSES takes care of backward adjustments or corrections when new information comes in. Starting from 2010, the HERD survey has collected academic R&D in both science and engineering and nonscience and nonengineering fields. However, figures are available on nonscience and nonengineering R&D funds since 2003, but they are not yet included in the total academic R&D expenditures. The next total academic R&D expenditure time series to be published will include these nonscience and nonengineering R&D components, and revisions will be made back to 2003. Similarly, NCSES also plans to revise the business R&D figures that are based on answers to questions on "projected R&D" once the actual R&D figures are reported the following year. Therefore, *National Patterns* users need to be careful when making comparisons across time and should consider using only the latest published data. Generally, there is a note in all the detailed statistical tables and *Data Updates* that warn the users about comparing figures from a recent report with those in previous reports.

Kafadar wanted to know if the uncertainty introduced through the use of survey estimates can be acknowledged by publishing uncertainty estimates in *National Patterns*. Boroush pointed out that the survey of FFRDCs and HERD are actually censuses, not surveys, and the Federal Funds Survey is nearly so, so the question is mainly about estimates from BRDIS. Even for BRDIS, the estimated sampling variances of the resulting estimates are small.[9] Boroush reported that NCSES staff have looked at uncertainty estimates when the issue was raised in the agency; they found that the revisions they made were often on the same order of magnitude, so the uncertainty intervals would need to reflect both sampling and nonsampling error.

Stephanie Shipp raised the issue of tabulations reporting science and engineering fields and socioeconomic objectives. She said that classifying R&D performed by such new taxonomies is going to be a challenge. Currently industrial R&D is broken down by the classification codes in the North American Industry Classification System (NAICS), and academic R&D is reported by science and engineering field. Federally performed R&D is the third largest sector, and the current breakdown for it is by agency and program. As mentioned above, the original targets for categorization of R&D expenditure by socioeconomic objectives and fields of science were government budget appropriations and academic R&D. Therefore, she suggested it will be challenging for NCSES to assign R&D expenditures to new taxonomies or nomenclature across all funders and recipients. John Jankowski responded that business R&D is mostly development and from a practical viewpoint it is difficult to assign development work to traditional science and engineering fields; thus, this breakdown is not very meaningful. He also added that asking companies to report their R&D by science and engineering fields was considered during the redesign process of BRDIS, but for conceptual reasons such an item was not included in the BRDIS survey.

INTERNATIONAL AND OTHER COUNTRIES' PUBLICATIONS ON R&D STATISTICS

Figures from *National Patterns* feed into various international publications and databases, such as OECD's main science and technology indicators; the science and technology data of the Institute of Statistics of the United Nations Educational, Scientific and Cultural Organization (UNESCO); and Eurostat's statistics database. As one primary purpose of the workshop was to investigate ways to improve the content and dissemination of *National Patterns*, it is important to understand how science,

[9] The statement that the coefficients of variation in BRDIS are small is generally justified by statistics that were provided to the steering committee by NCSES that have not yet been released. The major categories of expenditure typically had a coefficient of variation (CV) of less than 1 percent; however, for smaller disaggregated categories, the CVs were often much larger.

technology, and innovation (STI) data are collected and published by various international and national agencies or organizations. The material in this section combines background materials prepared for the workshop by staff of the Committee on National Statistics and workshop presentations given by Fernando Galindo-Rueda and John Jankowski.

Galindo-Rueda began by acknowledging and welcoming the challenge of representing the views of the international community and apologizing in advance for any potential omissions and reminding participants that his comments are his own personal remarks. He explained that he had sought feedback on *National Patterns* from colleagues and national experts in science and technology statistics who are responsible for producing R&D statistics. Although he received several suggestions for improvement and increased international comparability, the people he spoke with acknowledged that *National Patterns* is a model for many nations that produce R&D statistics. That is, the series not only produces national R&D statistics but also acts as a benchmark for other national and international STI agencies: *National Patterns* has been influential in shaping OECD's statistical guidelines since 1962. He urged workshop participants to consider its relevance to international producers and users of R&D statistics, considering how R&D statistics are reported worldwide and learning potential lessons.

Galindo-Rueda continued by providing some additional context and background on the R&D statistics collected and reported by OECD, Eurostat, and selected national agencies.

OECD

R&D statistics generated by OECD are based on three databases: analytical business enterprise research and development (ANBERD), research and development statistics (RDS), and main science and technological indicators (MSTI). The ANBERD database presents industrial R&D expenditure data broken down in 60 manufacturing and services sectors for OECD countries and selected nonmember economies.[10] The reported data are expressed in national currencies as well as by purchasing power parity in U.S. dollars, both at current and constant prices. ANBERD serves to provide analysts with comprehensive and internationally comparable data on industrial R&D expenditure. The member nations and observer economies provide data to OECD through the joint OECD/Eurostat International Survey on the Resources that is devoted to R&D. The database includes estimations that are drawn from the RDS database and other national

[10] See http://www.oecd.org/sti/anberd [February 2013].

sources. ANBERD is part of the family of industrial indicators produced by the Science, Technology and Industry Directorate at the OECD.[11]

The RDS database (see http://www.oecd.org/sti/rds [May 2013]) is the main source of R&D statistics collected according to the guidelines set out in the OECD's *Frascati Manual* developed by the Working Party of National Experts on Science and Technology Indicators.[12] It covers expenditures by source of funds, type of costs, and R&D personnel by occupation, shown in both headcounts and full-time equivalents (FTEs). It also includes data on Government Budget Appropriations or Outlays on R&D.[13] These data, too, come from the joint OECD/Eurostat survey. Series are available from 1987 to 2010 for 34 OECD countries and a number of nonmember economies. Information on sources and methods used by countries for collecting and reporting R&D statistics are provided in the sources and methods database.[14]

MSTI comprises a number of indicators based mainly on R&D expenditures, but also on R&D personnel and government R&D budgets. The set of indicators reflect the level and structure of the efforts undertaken by OECD member countries and seven nonmember economies (Argentina, China, Romania, Russian Federation, Singapore, South Africa, Chinese Taipei) in the field of science and technology since 1981. These data include final or provisional results as well as forecasts established by government authorities. The indicators cover financial and human resources devoted to R&D, estimates of governments' R&D budgets (GBAORD), selected patent indicators from the OECD patent database, indicators from the technology balance of payments database, and estimates of international trade in R&D-intensive industries. It is published biannually, and the database is publicly available online.[15] MSTI includes estimates of R&D expenditures and human resources for the OECD area, thus highlighting the importance of securing timely data from all OECD countries. MSTI outputs—for example, indicators such as gross domestic expenditures on R&D (GERD) as a proportion of GDP—are typically featured in sections within national publications devoted to the benchmarking of national results with other selected countries.

Another publication of OECD is the *Science, Technology, and Industry*

[11]See http://www.oecd.org/trade/stanindicatorsdatabase.htm [February 2013].

[12]The UNESCO Institute for Statistics also publishes R&D statistics for a broader range of countries, based on OECD, other regional and national sources for non-OECD members. Even though the *Frascati Manual* is the key international reference for R&D statistics collection and reporting, compliance with OECD guidelines varies across countries, particularly those outside the OECD area.

[13]See http://webnet.oecd.org/rd_gbaord_metadata/default.aspx [February 2013].

[14]See http://webnet.oecd.org/rd_gbaord_metadata/default.aspx [February 2013].

[15]See www.oecd.org/sti/msti [February 2013].

Scoreboard,[16] which has some features in common with *Science and Engineering Indicators* published by the National Science Board. It, too, is a biannual publication with detailed analysis of data. The *Scoreboard* not only draws on data collected by the OECD according to OECD standards, but also from other sources.

Eurostat

Eurostat is the Directorate-General of European Commission and its main function is to provide statistical information on European Union (EU) and associate states. Science, technology and innovation is one of the main themes of Eurostat's statistical portfolio.[17] R&D statistics are collected from national agencies according to EU legislation that compels countries to report specific statistics according to a set timetable, using definitions and methodologies laid out in the OECD *Frascati Manual*. To minimize the burden on countries, OECD and Eurostat coordinate their collection of national data through a common questionnaire, reporting, and monitoring protocol. Eurostat publishes data for non-EU countries, including the United States, based on OECD sources. Eurostat pays particular attention to quality reporting and the comparability of R&D data across EU member states, given the policy use of R&D data at the EU level.[18] The main themes of Eurostat's statistical portfolio are policy indicators; general and regional statistics; economy and finance; population and social conditions; industry, trade and services; agriculture and fisheries; external trade; transport; environment and energy; and science, technology, and innovation.

Statistics Canada

Statistics Canada is the Canadian federal statistical agency in charge of reporting R&D and other science and technology statistics. Its main counterpart to the U.S. *National Patterns* is *Gross Domestic Expenditures on Research and Development in Canada (GERD) and the Provinces*.[19]

R&D expenditures in Canada are estimated annually by type of sector, by sources of funds, and by science type, using a series of surveys supplemented by modeling and, in some cases, administrative sources:

---

[16] See www.oecd.org/sti/scoreboard [February 2013].

[17] See http://epp.eurostat.ec.europa.eu/portal/page/portal/science_technology_innovation/introduction [January 2013].

[18] See, for example, http://epp.eurostat.ec.europa.eu/portal/page/portal/sdi/files/t2020-20_tsdec320_Gross_Domestic_Expenditure_on_RD-DM.PDF [January 2013] and http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/Annexes/rd_esms_an12.pdf [January 2013].

[19] For the most recent issue, see http://www.statcan.gc.ca/pub/88-221-x/88-221-x2012001-eng.pdf [January 2013].

- Six sectors are covered: Business enterprises, federal government organizations, higher education organizations (including universities and affiliated teaching hospitals), private nonprofit organizations, provincial government organizations, and provincial research organizations.
- Sources of funds: Intramural R&D expenditures are spent within organizations performing the R&D. The organizations can fund their own R&D or undertake R&D on behalf of other organizations. The R&D performing organizations indicate the source of funds by sector for intramural expenditures. In the GERD matrix, the sources of funds data are shown by funding sector.
- Science type: R&D expenditures are spent by organizations performing in either the natural sciences and engineering and the social sciences and humanities. Only intramural R&D expenditures in the natural sciences and engineering by provincial research organizations and business enterprises are included in the GERD.

United Kingdom

The United Kingdom's national R&D statistics are produced by the Office of National Statistics (ONS) in its annual statistical bulletin. There is generally a lag of 2 years between the reference year and publication year. ONS draws together information on R&D spending in the public and private sectors, which includes business enterprises, government departments, higher education, private nonprofit organizations, and research councils.[20]

The statistical bulletin contains estimates by economic sectors:

- Business enterprise: Business enterprise R&D is derived from the results of the ONS's annual business R&D survey. Approximately 5,000 businesses are sampled from a reference list of known enterprises that do R&D.
- Higher education: Higher education R&D is estimated by the Higher Education Funding Councils for England, Scotland, Wales, and the Department for Education in Northern Ireland.
- Government: Government R&D is based on the returns of an annual survey of in-house R&D from all government departments and the addition of ONS estimates for R&D performed by local authorities.
- Research councils:[21] Research councils are included in the annual

[20]For the latest bulletin covering 2010 data, see http://www.ons.gov.uk/ons/dcp171778_258505.pdf [January 2013].

[21]For a description of research councils, see http://www.rcuk.ac.uk/Pages/Home.aspx [January 2013].

government survey. In order to provide additional information, however, their expenditures are shown separately in the data tables.

- Private nonprofit: Due to a planned review of the methodology used for the compilation of the R&D spent by the private nonprofit sector, estimates are currently based on a number of sources, including the total reported as the GOVERD ”other UK” spent by government, including research councils.

France

The agency responsible for collecting and publishing R&D statistics in France is the Education and Research Ministry. A six-page information note[22] produced by the statistical unit within the ministry summarizes the key R&D indicators and describes the evolution and structure of financial and human resources devoted to R&D in the French economy. A number of complementary tables are also available, providing additional detail.[23] The summary report places particular emphasis on international benchmarking of the French results and mapping the flow of resources from funding to performing sectors in the economy.

COMPARABILITY OF U.S. STATISTICS

Boroush had noted various areas in which NCSES has tried or is trying to make the data in *National Patterns* more internationally comparable. John Jankowski provided more detail in his presentation in the session on “International Comparability,” primarily responding to Galindo-Rueda’s comments on the differences between NCSES’s R&D statistics and analogous statistics from international organizations and other countries. He summarized the various efforts undertaken by NCSES, including redesigning the industrial and the academic surveys so that the estimates derived from these two surveys could meet the demands of the international science and technology community.

For BRDIS, Jankowski reported on the following changes that were made:

1. Social science R&D: The BRDIS questionnaire contains items asking companies to report the amount of social science R&D performed. It does not include R&D performed in the field of humanities, and NCSES

[22]A description in French is available at http://www.enseignementsup-recherche.gouv.fr/reperes [January 2013].

[23]They are available in French at http://www.enseignementsup-recherche.gouv.fr/reperes/public/chiffres/default.htm [January 2013].

explained to respondents that market research does not fall under the purview of social science R&D. Inclusion of social science R&D in the total R&D performed by the industrial sector increased the total industrial R&D by $500 million, 0.2 percent of the industry R&D total, and made the numbers internationally comparable. Two-thirds of the $500 million is reported by software publishers and computer design companies.

2. Capital R&D: Capital R&D is not part of total federal R&D reported in *National Patterns*. However, when NCSES reports the United States' R&D performance to OECD, capital R&D expenditure is included in federal R&D. To support this reporting, BRDIS explicitly asks companies to report their capital R&D expenditure. NCSES intends to make the information available by industry classification.

3. More detailed R&D funding data: The predecessor to BRDIS combined internal and external sources of nongovernment funding into a single category and no further details were requested from the respondents. BRDIS now asks companies to report not only their domestic expenses, but also their operations outside of the United States. Separate data are collected on company's internal sources of funding, as well as funding from other companies inside the United States; from companies located outside of the United States; and from several other nongovernment sources. In the 2010 BRDIS, a foreign parent was included as an explicit source of R&D funding to differentiate such support from other funding from companies located outside of the United States.

4. Expanded R&D personnel data: The *Frascati Manual* recommends that companies separately report headcounts and FTEs for researchers, technicians, and support staff. Total R&D personnel is the sum of researchers, technicians, and support staff (see Chapter 3). The predecessor to BRDIS contained items only on FTE R&D scientists and engineers. NCSES resolved the data gap by adding questions on the 2011 BRDIS on FTE researchers and total R&D personnel (headcount) by gender; occupation (scientists and engineers, technicians, support staff); and location, including foreign locations.

Janowski said the following changes were made to the Higher Education Research and Development Survey (HERD) when it was revised and renamed:

1. Humanities and other nonscience and nonengineering R&D: The predecessor to the HERD survey collected data for 1972-2009 on educational institutions that performed science and engineering R&D. In doing so, NCSES was collecting information on nonscience and nonengineering R&D performed by institutions that also performed science and engineering R&D but missing institutions that performed R&D but not science and engineering R&D. Beginning in 2010 (NCSES redesigned its higher

education R&D survey in 2010), the academic survey included institutions that exclusively performed nonscience and nonengineering R&D, thereby widening the scope of the survey. That category includes R&D performed in education, business, law, social work, and the humanities. The inclusion of social science R&D in BRDIS and the expansion of R&D fields in HERD increased the total domestic R&D figure by 1 percent.

2. Cost components of R&D: The 2010 HERD started to collect details on the cost of R&D, which includes statistics on personnel cost, materials, and equipment. This element was added primarily to help address data needs of the Bureau of Economic Analysis (BEA), which produces estimates of GDP if R&D is treated as an investment.[24]

3. More detailed R&D funding data: HERD survey, like BRDIS now has a question on foreign sources of R&D. It requests the total amount of R&D expenditure that came from a foreign source. There are no follow-up questions on disaggregating that number, i.e., the questionnaire does not ask the institutions to provide a breakout as to who those foreign sources were, e.g., foreign companies, foreign universities, foreign governments etc.

4. Expanded R&D personnel data: The predecessor to HERD contained a serious data gap in terms of collecting information on R&D personnel in the academic sector. To address this, the 2010 HERD began collecting data on researchers and R&D personnel headcounts. During the HERD redesign, the investigation process indicated that collecting FTE data would be extremely problematic. Given that, the approach taken was to collect data on principal investigators. As a result, providing information on FTE researchers or R&D personnel in the academic sector is still not possible, but one can get headcounts of principal investigators and other R&D personnel.

[24]The National Income and Product Accounts (NIPAs) do not treat R&D and other intangibles as investment. BEA's R&D satellite account provides the means to separately identify the contribution of R&D to GDP growth. The account shows how GDP and other measures would be affected if R&D spending were "capitalized," that is, if R&D spending were treated as investment rather than as an expense. It was developed with support from NSF's Division of Science Resource Statistics. In December 2010, BEA released its revised national statistics, such as real GDP, real gross domestic income, national savings, aggregate returns to R&D assets, R&D investment, R&D output by performer, and input price indexes from 1959 to 2007. BEA plans to incorporate R&D spending as investment into its core accounts in 2013 as part of the comprehensive revision of the NIPAs.

3

Users' Needs

Three workshop sessions were devoted to the content of *National Patterns*. The first, "*National Patterns* Purposes and Uses," featured panelists who represented various categories of data users: the legislative and administrative branches of the federal government, policy analysts from organizations concerned with science and engineering policy, academics interested in the science of science policy, and people from the international science and engineering community. The panel had been asked to address, from their own perspectives, the utility of *National Patterns* and to indicate how it might better address their current and anticipated future needs.

In the second session, "Advances in International Comparability of *National Patterns* Data and Reports," the panelists examined in what ways *National Patterns* was and was not comparable with reports on R&D from countries that provide substantial support for R&D. Three issues that are often raised in this context are (1) the categorization of R&D funding by socioeconomic objectives, (2) the categorization of R&D by science and engineering fields, and (3) the tabulation of capital expenditures in support of R&D.

The third session, "Reporting of Additional Variables," addressed the content of *National Patterns*. While the panelists in the first session were directed to focus their remarks (but not exclusively) on variables that were already collected on the primary National Center for Science and Engineering Statistics (NCSES) censuses and surveys of R&D, this session looked to other possibilities. The steering committee was interested in whether variables that are not currently available would, if tabulated, be useful to *National Patterns* users. It was recognized that making major changes to existing censuses and surveys, including adding to respondent burden, should generally be avoided, but knowing what users need and would like to include in *National Patterns* could direct longer term decisions on census and survey content, as well as access to other sources of such information.

PURPOSES AND USES OF *NATIONAL PATTERNS*

In the workshop session on this topic, participants heard from five panelists, representing different kinds of users: Kei Koizumi, White House Office of Science and Technology Policy (OSTP); David Mowery, University of California, Berkeley; Martin Grueber, Battelle; Charles Larson, Innovation Research International; and David Goldston, Natural Resources Defense Council.

Kei Koizumi

Kei Koizumi summarized the use of *National Patterns* data by OSTP. A key theme of his presentation was the need for timely data. As assistant director for federal R&D, he is an extensive user of *National Patterns* information, and the R&D figures that appear in *National Patterns* are a vital tool in understanding the current R&D situation. In particular, given the goal set by President Barack Obama of 3 percent of the nation's gross domestic product (GDP) invested in R&D (Obama, 2009) during his administration, for Koizumi the ratio of R&D to GDP is the most important statistic in *National Patterns* reports.

Koizumi said that state-level R&D expenditure and funding is also of great interest, especially to people like him who are concerned with tracking regional economic development and developing regional innovation strategies. Koizumi considers *National Patterns* a one-of-a-kind product because it amalgamates information across surveys, but OSTP's use of R&D data from NCSES is not limited to *National Patterns*. As the need arises, data from the component surveys and censuses are also used for policy-making purposes.

Koizumi's overall comments suggested that receiving data 3 years after the reference year is a frustrating experience for many users and, therefore, the more timely release of data should be examined for improvement. Among other areas of improvement, he mentioned that state-level data could be made more useful by publishing both additional R&D data at the state level and, when possible, R&D data for areas within states. He also expressed the concern that *National Patterns* does not provide any way of understanding the role played by ARAA (the American Recovery and Reinvestment Act of 2009) investments in R&D.

Koizumi also pointed out three areas in which *National Patterns* falls short and urged NCSES to explore new ways to address them. First is the congruence of information from the Federal Funds Survey (see Chapter 2) and information reported by various agencies and departments. Second is the categorization of business and federal R&D data by science and engineering fields. Third is the development of variables denoting innovation and finding good ways of internationally comparing such non-R&D data.

He is looking forward to the information that is, and will be, available from the redesigned Business R&D and Innovation Survey (BRDIS). He concluded his presentation by referring to future additions to the federal government's Strategy for American Innovation (see National Economic Council, 2011) in the form of administrative policy initiatives which will be better informed if there are better and more timely data on science, technology, and innovation at national and regional levels.

David Mowery

David Mowery discussed the needs of the academic user community for information on R&D. Being an economist and historian interested in science and technology issues, Mowery said that he considers *National Patterns* to be a unique product. It produces a long, stable time series for R&D expenditures and funding that is not available elsewhere, and it also provides a comprehensive performer/funder matrix that is valuable to understanding the changes in the R&D performer and funding sectors. Also, he said, *National Patterns* helps in widening a myopic view of many of the policy makers who focus entirely on the R&D-to-GDP ratio. *National Patterns* tabulations go beyond this single indicator and provide information on underlying structural changes, such as the rise in the share of academic-funded R&D or the recent decline in R&D performed by large-sized firms (see National Science Foundation and National Center for Science and Engineering Statistics, 2005, Table 7).

However, Mowery said, the publication does not satisfy the need to better understand and track new and emerging areas of R&D and innovation activity, such as photonics and nanotechnology. He also expressed concern about the uncertainty or error generated by the various survey-based estimates and hoped that, because the data are reported at higher levels of aggregation (national and states), the aggregation removes some of that noise on a percentage basis.

Mowery then raised the issue of content and dissemination. Because the statistical content of *National Patterns* is restricted solely to R&D expenditures and funding, it is duplicative of much of what appears in the biennial *Science and Engineering Indicators* (published by the National Science Board): see Figure 3-1. The figure plots two values. First, the number of tables published in *National Patterns* is plotted, which has decreased

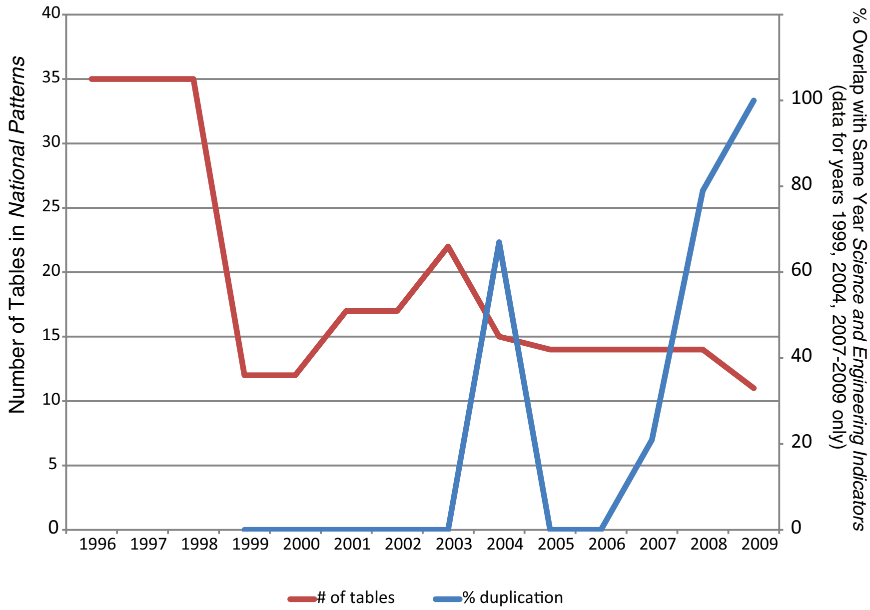


FIGURE 3-1 Duplication of information in *National Patterns* and *Science and Engineering Indicators*.
SOURCE: Mowery (2012, Figure 1).

from 35 to 26 from 1996 to 2009. Second, it plots the percentage of tables appearing in *National Patterns* that also appeared in *Science and Engineering Indicators*, which has increased from less than 25 percent in 2004 to 100 percent in 2009.

In its first issue in 1994, *National Patterns* contained tables and charts on R&D resources, which included R&D expenditures, R&D funding, and scientists and engineers involved in R&D. Tables on these same topics were published in 1995 and 1996. There was a change in the 1997 data update: it contained tables on R&D expenditure and funding and on how the United States is performing in R&D relative to the rest of the world. The series went back to its original statistical displays in 1998, but in 1999 it reverted back to the 1997 format and has continued that format. In addition, there has been a reduction in the number of tables, as less information has been provided in the data updates. Several items that appear in the 1994-1996 and 1998 volumes are no longer part of the current series: the breakdown of academic R&D and R&D expenditures at university-administered federally funded research and development centers (FFRDCs) by science and engineering fields, disaggregation of industrial R&D by industry type and firm size, and the cost per R&D scientist/engineer by industry and company size. Mowery noted, however, that most of that information is now available in IRIS, SESTAT, and WebCASPAR, NCSES's online communal tools.[1] The 1994-1996, 1998, and 2003 data updates also contained interesting analysis and charts. The 2004-2009 data updates did not follow up on the earlier analysis and charts, and analysis of R&D data is now restricted to the *Info Briefs*.

Mowery said that the first *Science and Engineering Indicators* was published in 1972. The 1994 data update of *National Patterns* reported that it complements the *Science and Engineering Indicators* in those years that it is not published. The 1997 data update made it clear that almost all the information in the report makes its way into *Science and Engineering Indicators* of the next year. Currently, the situation is not very positive, he said, since there is close to 100 percent duplication with *Science and Engineering Indicators* in the years that it is released, thereby making the information in *National Patterns* redundant.

Mowery offered two suggestions to improve the content of *National Patterns* and to make it more complementary to *Science and Engineering Indicators*. One is that the series go back to its original data topics, which includes tabulation of data on human capital. The other is to include the breakdown of business R&D by industry type, which is not currently published in *National Patterns* but as a separate *Info Brief*. In terms of dissemination policy, Mowery suggested that *National Patterns* be made a biennial publication coming out in those years when *Science and Engineering Indicators* is not published and be a complement to it.

Martin Grueber

Martin Grueber represented users who are familiar with the individual cell entries of *National Patterns* tabulations and their quality, given that his job is to forecast global R&D funding. Battelle, in collaboration with *R&D Magazine*, produces forecasts of global R&D funding. The 2012 global R&D funding forecast was Battelle's 44th and *R&D Magazine's* 54th publication of the forecast series.

In his presentation, Grueber described details of the forecast calculation process and how *National Patterns* data are used in arriving at these forecasts. During production of the 2012 forecast, the latest *Data Update* of *National Patterns* that was available was for 2008. Hence, he had to use 3-year-old data to forecast 4 years ahead. This time lag highlights

[1]IRIS is the Industrial Research and Development Information System; SESTAT is the Scientists and Engineers Statistical Data System; WebCASPAR is the Integrated Science and Engineering Resources Data System.

users' discomfort when there are long delays in this annual publication. But Grueber praised the historical corrections in the series, which helps in improving forecasts. Grueber also acknowledged that the time series from *National Patterns* helps him validate various homogeneity assumptions, assuming that the ratios of elements of the source-performing matrix are stable over time.

Grueber said that he relies not only on data from the National Science Foundation (NSF), but also on science and technology data from the White House OSTP, federal agencies, OECD, the European Union, the International Monetary Fund, various trade and technical associations, the media, and other third-party data providers. In addition, Battelle conducts its own surveys. Other surveys that provide primary data to the forecast process are *R&D Magazine* reader surveys and the Global Researcher Survey. Battelle also collects company data from annual reports and filings with the Security and Exchange Commission (SEC). Grueber is also in direct touch with NCSES staff members Mark Boroush and Ray Wolfe, who provide him with insights and verification of some his assumptions.

As does *National Patterns,* the forecast publication series contains a R&D funding source and R&D performer matrix: see Table 3-1. Three important elements are missing from the funding source/performer matrix of *National Patterns*: (1) industry funding to FFRDCs; (2) other government funding, such as state and provincial governments' contributions to R&D funding to industry, nonprofit organizations, and FFRDCs; and (3) R&D funding by nonprofit organizations to industry and other nonprofit organizations. The first is not distinctly reported in *National Patterns* but is subsumed under federal funding to FFRDCs as relatively small, given the size of nonfederal contributions to the FFRDCs,[2] even though there is sufficient evidence to conclude that this cell is not empty. Grueber pointed out that a nonprofit organization like Battelle is involved in research being conducted in FFRDCs, which in turn is funded by companies. Thus, there is important work done by the industrial sector that is not recognized by *National Patterns*.

The second missing element would be of great interest to state economic development offices, since they are keen to understand the R&D performance of their states. Direct state funding to R&D in the private sector (both nonprofit and for-profit entities) has increased over the last decade. Grueber gave the example of Ohio's "Third Frontier Initiative," which is a major component of the state's Office of Technology Investments. It provides funding to technology-based companies, universities,

[2]In fiscal 2010, NSF's survey of FFRDCs showed that 97.3 percent of all their funding came from the federal government; less than $450 million came from other sources: see National Science Foundation (2012e, Table 5).

TABLE 3-1 R&D Funding Source and R&D Performer Matrix

Estimated Distribution of U.S. R&D Funds in 2012
Millions of Current U.S. Dollars (Percent Change from 2011)

Source	Performer					
	Federal Gov't.	FFRDC	Industry	Academia	Non-Profit	Total
Federal Government	$29,152 -2.51%	$14,666 -3.69%	$37,577 -2.42%	$37,440 0.93%	$6,817 -2.29%	$125,652 -1.61%
Industry		$202 2.20%	$273,487 3.37%	$3,868 26.49%	$2,129 8.89%	$279,685 3.75%
Academia				$12,318 2.85%		$12,318 2.85%
Other Government				$3,817 2.72%		$3,817 2.72%
Non-Profit				$3,491 2.70%	$11,055 2.70%	$14,546 2.70%
Total	$29,152 -2.51%	$14,868 -2.36%	$311,063 2.63%	$60,934 2.85%	$20,001 1.55%	$436,018 2.07%

SOURCE: Grueber and Studt (2011, Table 4).

nonprofit research institutions, and other organizations in Ohio to create new technology-based products, companies, industries, and jobs.[3] Grueber acknowledged, however, that in the context of national R&D, performance state-level R&D funding to private-sector efforts is likely small and it is understandable that there is not a separate data series in *National Patterns*.[4]

The third missing element, funding by nonprofit organizations to industry and other nonprofit organizations, is a serious data gap and a challenge for NCSES: there has not been a survey on the nonprofit sector since 1997. As NCSES is relying on 15-year-old data to calculate estimates for the nonprofit sector, there is the danger of missing the changes that have taken place in this sector, especially for nonprofit FFRDCs. Grueber observed that there has been substantial flow of dollars from the industrial sector to nonprofit organizations, though this is still a relatively small fraction of total R&D. He pointed out that the dynamics in the funding and performing sectors have changed, and NCSES is missing out on these changes because it is still following a traditional performer/funder matrix.

Companies often restate their R&D expenditures in their subsequent SEC filings for accounting purposes. Grueber expressed concern that there is currently no mechanism that can help NCSES update its business R&D expenditure and funding time series as companies revise their SEC filings. In contrast, NCSES is able to update federal R&D expenditure and funding time series when similar issues arise. He is looking forward to the changes that will take place in business R&D and academic R&D data when more detailed extensions (beyond traditional science and engineering fields) are included in *National Patterns* as a result of changes in the BRDIS and Higher Education Research and Development (HERD) surveys. Grueber concluded his presentation by commending BRDIS for starting to look at the structure of foreign investment and investment made by foreign companies in the United States, which in the future might result in a change to the source/performer matrix with the inclusion of a column on "sector abroad."

Charles Larson

Charles Larson focused on new initiatives for *National Patterns* that he said could aid in the process of better directing U.S. innovation and competition policies. His talk was inspired by the *Science and Engineering*

---

[3]For more information, see http://development.ohio.gov/bs_thirdfrontier/default.htm [October 2012]. Grueber noted that Batelle receives some funding from this intiative.

[4]*National Patterns* captures the R&D contribution from state and local governments to academic institutions and the business sector. State and local government is formally a part of the funding sources tracked in the academic and business R&D surveys, but the numbers are not reported explicitly: see National Science Foundation (2013, Table 3 Notes).

Indicators: 2010 Digest (National Science Board, 2010): it said that the United States holds a preeminent position in science and engineering in the world, but that the edge is slipping, while other countries are increasing their R&D spending in education. Larson referred to the view expressed by Richard N. Foster (formerly of McKinsey and Company) that "we need to learn the lesson of the winners" (see Foster, 1986; Foster and Kaplan, 2000) and gave examples of how institutions and policies contribute to the growth of the nation. The introduction and development of courses on the management of technology and entrepreneurship by U.S. universities has helped the United States' lead in competitiveness, and this strategy has been adopted by other countries.

Larson noted that in the world competitiveness rankings produced by the IMD Business School in Switzerland, the United States was the top competitive nation from 1995 to 2011 but came in second to Hong Kong in 2012.[5] Institutions and policies that encourage economic freedom and entrepreneurship are the hallmarks of U.S. competitiveness, he said. This point is further reinforced by the economic freedom rankings published by the Heritage Foundation (in partnership with the *Wall Street Journal*), in which the United States remained in the top five until 2009 but ranked only tenth for the first time in 2012.[6] Hence, even though policies and strategies adopted by United States have helped it to be in the top group, there has been a shift in the order, which is becoming a concern for U.S. policy makers and business leaders. Larson said that in such an environment it is all the more necessary to analyze and publicize the information on global competitiveness.

Larson mentioned three reasons cited by the IMD Business School as contributing to U.S. leadership in competitiveness: (1) its unique economic power, (2) the dynamism of its enterprises, and (3) its capacity for innovation.[7] The third criteria, the capacity for innovation, is crucial. Larson pointed out that innovation and R&D are different: "R&D converts money into knowledge; innovation converts that knowledge back into money." In addition, he said, the factors responsible for raising R&D investment are different from those encouraging innovation. He illustrated this by showing 2010 rankings by Booz & Company (see Jaruzelski, Loehr, and Dehoff, 2011) of the largest R&D investors and the most innovative firms in the world: there was no relationship among their rankings. He said that for innovation to take place successfully, the management of human

[5]For more information, see http://www.imd.org/news/IMD-announces-its-2012-World-Competitiveness-Rankings.cfm [October 2012].

[6]For more information, see http://www.heritage.org/index [January 2013].

[7]For more information, see http://www.imd.org/research/publications/wcy/World-Competitiveness-Yearbook-Results/# [October 2012].

resources is the key, along with strategic alignment and a culture that supports innovation.

Larson added that government policies have a key role in promoting innovation and economic competitiveness. These policies include funding for science and technology and stimulating interaction on R&D between government laboratories, universities, and businesses. Also, regulations have a great influence on business R&D and its success, he noted, citing an article on "the culture of 'no'" in some European countries.[8] He suggested that NCSES move from reporting only R&D investment to developing additional indicators on success factors in management practices for R&D and innovation. He added that collecting data on the impact of risk, seed capital, and labor regulations on investment in innovation can be of tremendous value to businesses and for informing economic and financial policy decisions.

The recent report, *Rising to the National Challenge: U.S. Innovation Policy for the Global Economy* (National Research Council, 2012b), proposed a review or renewal of U.S. investments in the "pillars of innovation." It concluded that the nation's economic growth and national security depend on renewed investments and sustained policy attention. To achieve these objectives, policy makers require a better understanding of how institutions and laws encourage innovation and competitiveness. *National Patterns* can act as a key tool in this process.

In conclusion, Larson urged that NCSES consider several specific actions:

- Make *National Patterns* broader, deeper, and more timely to serve the national interest.
- Additional data are needed on success factors in management practice for R&D and innovation.
- Analyze and publicize the criteria that enable global competiveness for the benefit of U.S. policy makers and business leaders.
- More data are needed on the factors involved in making R&D more effective in stimulating innovation.
- New data are needed on the impact of risk, seed capital, and labor regulations on investment in innovation.
- New data are needed on measuring return on R&D investment and innovation.
- More data are needed on the numerous factors of R&D and innovation success in a form that can be utilized more easily by business.

[8]See http://www.economist.com/node/21559618; http://www.washingtonpost.com/world/europe/in-france-entrepreneurs-battle-culture-of-no/2012/09/01/58d12e9a-f287-11e1-adc6-87dfa8eff430_story.html [January 2013].

David Goldston

The final speaker of this session was David Goldston, director of government affairs for the Natural Resources Defense Council. From 2001 through 2006, he served as chief of staff for the Committee on Science of the U.S. House of Representatives, the culmination of more than 20 years on Capitol Hill working primarily on science policy and environmental policy. He first commented on some of the points of the previous presenters and then considered the science and technology policy questions that policy makers grapple with.

Responding to Koizumi's presentation that policy makers are very much focused on the ratio of R&D to GDP, Goldston expressed concern that it is a myopic view. The meaning of that ratio is not very clear to economists, industrial researchers, or science and technology policy makers. He suggested that *National Patterns* could be a platform to produce a wider set of science and technology or R&D indicators. He said he agreed with Mowery on two points. First, along with R&D investment, one should look at other factors, including unemployment rates and job creation, to obtain a holistic picture. Second, he agreed on the importance of including new and emerging fields in the current taxonomy of R&D expenditure and funding. He noted that Larson's suggestions on new variables were interesting but would be difficult to collect.

Goldston said he is concerned about the limitations of the data in *National Patterns*. The series publishes R&D expenditure and funding by character of work: basic, applied, and development. But academic R&D is not disaggregated by science and engineering fields; therefore, it is hard to understand the amount of R&D investment in interdisciplinary research, transformational or high-risk research, and translational research.

Goldston then turned to major science and technology policy questions that go beyond utility and limitations of *National Patterns*. He offered several important questions that cannot be answered with the current data on R&D:

1. Do we know anything about the impacts of different fields so that policy makers know how much to allocate to various fields: for example, what would constitute a balance between the biological and physical sciences?
2. How many scientists and engineers does the United States need? An index that indicated when the United States is facing a shortage or surplus of scientists and engineers would be extremely valuable.
3. What is happening with younger researchers, especially in terms of their ability to get federal funding?

4. What are current salary figures and their effect on career choices and residence choices of foreign students getting a U.S. science or engineering degree?

5. How internationally comparable are the figures on human resources in science and technology given the differences in quality of training?

6. In the field of energy, is there a dearth of innovative ideas or do bottlenecks exist in the transfer of innovative ideas to marketplace? Do such bottlenecks arise from the supply side, the demand side, or labor relations?

7. Where is the "valley of death" and what kind of cycle is it currently in?[9] What kind of funding or other solutions would there be to bridge it?

In general, Goldston said he is concerned about the ability to answer questions concerning how technology and science education lead to the economic growth of a nation. What is the model of economic growth? It is known that investing in technology and science education raises productivity, but nobody is aware of the exact mechanism. Is this lack of knowledge a shortcoming from the analysis side or the data collection side? Although this question is broader than *National Patterns*, it is clear that *National Patterns* has a role to play in answering it.

ADVANCES IN INTERNATIONAL COMPARABILITY OF *NATIONAL PATTERNS* DATA AND REPORTS

This workshop session featured presentations by Fernando Galindo-Rueda, head of the Science and Technology Indicators Unit at OECD's Directorate of Science, Technology and Industry, and John Jankowski, director of the R&D statistics program at NCSES. Because Jankowski's presentation was primarily a response to Galindo-Rueda's comments on NCSES's R&D statistics, it is discussed in Chapter 2.

Galindo-Rueda began by reminding participants that the use of NCSES's R&D statistics is not limited to U.S. policy makers, economists, and science and technology policy analysts. The international science and technology community is very interested in knowing how their respective nations are performing relative to the United States. Moreover, because the United States accounts for a large share of the OECD's R&D efforts, a comparable and timely U.S. estimate is a necessary input for the entire OECD.

[9] "Valley of death" is a metaphor used to refer to the funding gap faced by innovators and investors. The funding gap takes place in the intermediate stage of the innovation process, between basic research and the commercialization process: it is a trough between two crests, a slump in the funding flow (Ford, Koutsky, and Spiwak, 2007; also see Branscomb and Auerswald, 2002).

Galindo-Rueda also reminded participants that one of the issues mentioned in the charge to the steering committee for the workshop was to assess the comparability of NCSES's R&D statistics with those produced by international organizations and agencies, including OECD, UNESCO, and Eurostat. Galindo-Rueda first explained his team's role in collecting and reporting R&D statistics, focusing on how *National Patterns* differs from international publications (see Chapter 2). Galindo-Rueda then discussed efforts to achieve greater international comparability. Two of the main current differences in *National Patterns* with respect to OECD data (which are published for 34 OECD members and 7 non-OECD economies) are the treatment of capital expenditures for R&D and information on R&D funding sources. The OECD's *Frascati Manual* (see Chapter 2) recommends the collection and reporting by countries of both current expenditures and capital expenditure related to R&D for a given year. NCSES collects data on current expenditures and a book estimate of capital depreciation.

When NCSES submits data on R&D expenditures to OECD, depreciation estimates are removed without a compensating adjustment for capital expenditures. This results in an underestimate of total R&D expenditures for the United States relative to other countries. Galindo-Rueda suggested additional reporting for capital expenditures, which is now feasible for the business sector because NCSES's BRDIS asks survey respondents for this information. A further step that will add value to *National Patterns* would be publishing capital expenditures by funding source. In terms of funding source, Galindo-Rueda reiterated what Martin Grueber said about the absence of an "abroad sector" in the data, a big information gap in the current series. For example, almost 30 percent of Israel's national R&D is funded by the rest of the world: see Figure 3-2. Austria, Ireland, and United Kingdom have 15 percent or more of their R&D funded by other nations. (In the case of Austria, the percentage is large because of major investments by German companies.) This variable has the potential to be a policy-relevant indicator.

Another potentially useful indicator would be R&D investment of domestic U.S. entities in R&D-performing units located abroad. The entities could be organizations or institutions or companies or even national governments. Drawing on his experience with R&D expenditure and funding reported by various nations, Galindo-Rueda pointed out that most countries do not provide the performer/funder matrix by character of work (i.e., basic, applied, and experimental development, as does NCSES), but they do tend to provide detailed information by type of cost, separating employment costs from other current and capital expenditures.

In addition to data on R&D financial resources, there are other differences between *National Patterns* and international R&D statistics. There is

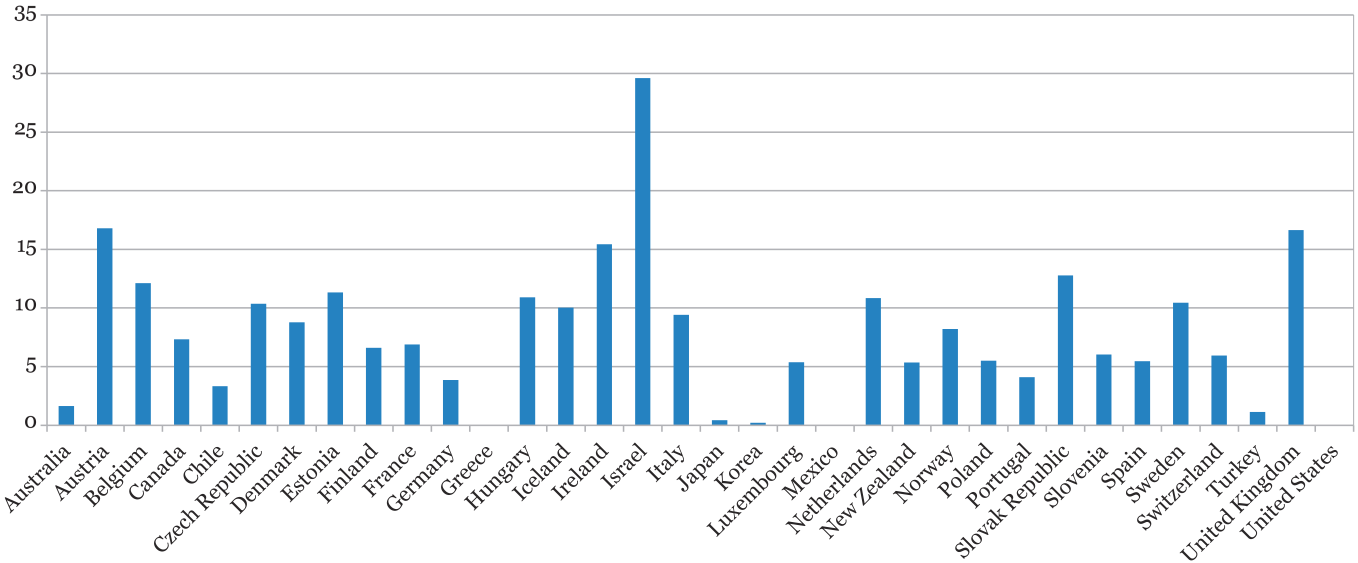


FIGURE 3-2 Percentage of gross domestic expenditures on R&D funded by rest of the world, 2009.
NOTES: Data for Australia, Chile, Iceland, Israel, and Switzerland are for 2008. Data are missing for Greece, Mexico, and the United States. Data are derived from OECD's main science and technology indicators database.
SOURCE: Galindo-Rueda (2012, Figure 3).

a lack of information on R&D personnel and researchers[10] (see Chapter 2), and Galindo-Rueda said he hoped that this issue could be addressed better with the redesigned BRDIS and HERD surveys. Information on human resources in science and technology are used as a normalizing factor and are frequently requested by many users. In the field of bibliometrics, for example, analysts look at the data on researchers to investigate research productivity. OECD integrates information on R&D investment and researchers to produce a range of figures and graphs: for an example, see Figure 3-3. This figure highlights research intensity either as a measure of R&D expenditure relative to GDP or as a measure of researchers relative to population size. The figure shows a close relationship between the two measures, though with some outliers. By combining science and technology variables, one can investigate a number of factors that can aid policy decisions. Galindo-Rueda also highlighted the problems associated with measuring human capital in science and technology in terms of full-time equivalents in comparison with headcounts, as both of these measurements present difficult analytic issues. As Schaaper (2012) notes:

> Headcount data are data on the total number of persons who are mainly or partially employed on R&D. Headcount data are the most appropriate measure for collecting additional information about R&D personnel, such as age, gender or national origin. But R&D activity can be a primary activity or secondary activity of R&D personnel. It can also be a significant part-time activity for university teachers or postgraduate students. To take into account such factors number of persons engaged in R&D is also expressed in full-time equivalents (FTEs). Therefore FTE is the true measure of the volume of R&D activity performed by R&D personnel. Across nations there exists diversity of methods that are used to calculate full-time equivalents of R&D activity and the formula also varies across sectors, which leads to problems in comparisons. But FTE is key to adequately calculating national R&D expenditure as Researcher's salaries are a significant part of it. National R&D expenditure should only include the proportion of the salaries devoted to R&D as inclusion of salaries based on headcounts would lead to significantly overestimated value of national R&D expenditure.

[10]The category of R&D personnel comprises teachers, technicians and equivalent staff, and other supporting staff. Researchers are professionals engaged in the conception or creation of new knowledge, products, processes, methods, and systems and in the management of such projects. Technicians are staff whose main tasks require technical knowledge and experience and they perform scientific and technical tasks involving the application of concepts and operational methods, normally under the supervision of researchers. Equivalent staff are those who perform the corresponding R&D tasks under the supervision of researchers in the social sciences and humanities. Other supporting staff includes skilled and unskilled craftsmen and secretarial and clerical staff participating in R&D projects or directly associated with such projects.

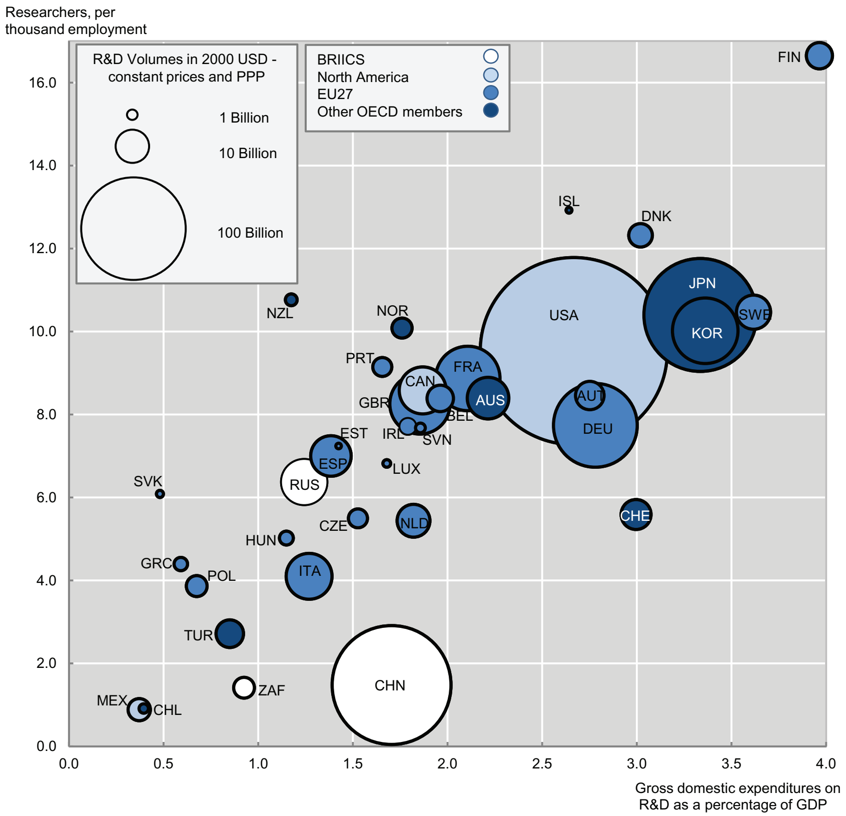


FIGURE 3-3 A comparison of researchers per thousand of employers and R&D expenditures as percentage of GDP: Multiple years.
NOTE: Data are from 2008 for Australia, Canada, Chile, France, Iceland, Korea, South Africa, and Switzerland. Data are from 2007 for Greece, Mexico, New Zealand, and the United States. BRIICS = Brazil, Russia, India, Indonesia, China, and South Africa; EU = European Union; PPP = purchasing power parity.
SOURCE: OECD, main science and technology indicators database, June 2011, see http://dx.doi.org/10.1787/888932485196 [May 2013].

Galindo-Rueda added that NCSES publishes values for gross domestic expenditure on R&D (GERD) in the international comparability table of *National Patterns*. Most national publications he is aware of typically contain such a section, drawing on data collected through official channels by OECD from its members and other economies. This section is important to domestic users in all countries as international benchmarking of R&D efforts has been one of the main purposes of R&D data reporting.

However, he said, there is some potential for confusion by users who may not fully appreciate the difference between the core series on R&D expenditures that is reported in *National Patterns* and the adjusted GERD series used for international comparisons. For the United States, GERD values are marginally different from reported total national R&D expenditures: the difference is driven by the omission of capital depreciation costs and a small adjustment to federal R&D in the U.S. GERD estimate. Galindo-Rueda said that NCSES may want to continue publishing a figure of R&D expenditures that incorporates capital depreciation costs to maintain the time series comparability, while reporting an improved GERD estimate in line with the *Frascati Manual* guidelines using the newly available data.

Being an international user of the U.S. R&D statistics, he looks forward to more timely data from NCSES. The current omission of U.S. data results in an incomplete analysis because one-third of the world's R&D is performed in the United States (see National Science Board, 2012, Ch. 4, Fig. 4). From his experience, Galindo-Rueda said, European nations are very timely, and, among Asian nations, China provides up-to-date information. In conclusion, Galindo-Rueda highlighted the fact that *National Patterns* is a global statistical public good that is widely used by the international science and technology community. It is a key component of OECD's R&D statistics and a valuable resource for analysts because it offers a long time series. NCSES's efforts toward redesigning two of the major input surveys and the consequent survey findings will provide assistance to OECD in terms of reviewing the *Frascati Manual* guidelines.

REPORTING OF ADDITIONAL VARIABLES

Although the topic of possible additional variables was appropriately part of several workshop sessions, the steering committee for the workshop decided to devote a full session to it to stimulate more thought on an issue that is expected to become increasingly important over time. Adding new variables that reflect changes in the field will maintain the relevance of *National Patterns* over time. Kaye Husbands Fealing, of the Committee on National Statistics, National Research Council (NRC), provided the single presentation of this session. Her goal was to examine what variables that were not currently collected on any of the five censuses or surveys that feed into *National Patterns* would, if available and tabulated, be useful to *National Patterns* users. As study director of an NRC Panel on Developing Science, Technology, and Innovation Indicators for the Future[11] given

[11]This study was also sponsored by NCSES and is being conducted under by the NRC's Committee on National Statistics in collaboration with the Committee on Science, Technology, and Economic Policy; its report is expected in 2013.

that this panel was charged with examining the status of NCSES' science, technology, and innovation (STI) indicators, Fealing was in a position to describe the statistics that her panel thought would be useful to produce to understand innovation activities in the United States and worldwide.

As mentioned by Charles Larson, Fealing said, there is an important difference between R&D statistics and indices for innovation. The statistical tabulations for *National Patterns* are mainly information on R&D stocks; in contrast, indicators on innovation activities include measures of R&D flows, science and technology outputs and trade, knowledge networks, and human capital stocks and flows. The hope is to obtain data not only on the current status of R&D but also of trends.

Fealing noted the challenges faced by the panel in devising a conceptual framework for scientific discovery and technological innovation. This framework needs to include not only the traditional elements—inputs, outputs, and effects—but also the institutional elements that influence the functioning of the system. The panel was also tasked with providing the best priority framework to NCSES that can guide the development of STI indicators for such a system. Fealing showed the audience an example of a model for a national innovation system and pointed out that there is a lack of information on linkages or spillover effects. Her experience with the panel has convinced her that data on spillover effects between actors and activities in the system and the resulting outputs and outcomes are particularly useful for informing policy decisions. Another data gap of concern is subnational—STI statistics such as state and local funding to industrial R&D performers—as noted earlier in the workshop.

In its interim report (National Research Council, 2012a), the panel's recommendations to NCSES focused on improving or developing new indicators on:

1. how labor force mobility is related to STI activities by exploring existing longitudinal data from various surveys,
2. innovation and firm size based on data from the restructured BRDIS,
3. understanding firm dynamism by matching BRDIS data to surveys from the Census Bureau and Bureau of Labor Statistics, and
4. indicators on payments and receipts for R&D services between the United States and other countries by using the BRDIS data on firms' domestic and foreign activities.

The panel also recommended that NCSES host working groups to further develop subnational STI indicators and to fund exploratory activities on frontier data extraction and development methods.[12] Fealing also stressed the importance of the timeliness and reliability of *National Patterns* data. She pointed out that timely data is another aspect of data quality and very important to users of STI data and statistics.

HOW TO IMPROVE *NATIONAL PATTERNS*: DISCUSSION

One impression that was evident from these sessions is that the user community of *National Patterns* is heterogeneous regarding the specific areas users would like to see addressed in this series of reports and that satisfying all users would be a challenge. Yet the current *National Patterns* reports have clearly been successful in satisfying user needs by providing quality information, including at considerable levels of detail when justified by data quality. The range of proposals for improving *National Patterns* for users varied widely from focusing on only a single indicator—the ratio of R&D expenditure to GDP—to broad questions on how investment in STI leads to economic prosperity.

One issue mentioned by virtually all the participants is the need for timely publication of the series. Fealing made the interesting observation that one need not consider timeliness and quality in opposition: rather, one can consider timeliness as one of several attributes of quality data.

In terms of more content, all the presenters had different wish lists, including more information on human capital, better innovation indicators, and more detailed analysis of data instead of just reporting R&D figures. Possibly the most important lesson from these three sessions is that *National Patterns* would benefit from finding some way of keeping abreast of users' needs and wishes so that it can be modified over time to remain as relevant as possible to users.

In response to Mowery's call for less duplication, Koizumi said that the duplication of topics and tables is inherent because NCSES produces separate tables and reports based on estimates from each survey that feeds into the series. The agency also conducts surveys on graduate students, postdoctoral researchers, and nonfaculty researchers in science and engineering. As noted in the sessions, *National Patterns* contained more comprehensive information in the 1990s, with a subsequent shift in the topics included in the publication to only R&D expenditure and funding. Jankowski said that this was done because the agency determined that science and engineering topics had more in common with topics covered in the series. This is a common conundrum of federal statistical agencies: reducing statistical output to

[12]Frontier tools and methods are those used to extract data and develop new datasets. Examples of such methods include nowcasting, netometrics, CiteSeerX, Eigenfactor, and Academia.edu.

avoid duplication can lead to user dissatisfaction. Many users of *National Patterns* preferred the publication to *Science and Engineering Indicators* in the 1990s, but there has been a shift of preference in the last decade.

Regarding timeliness, Karen Kafadar wondered whether NCSES could produce flash estimates or preliminary estimates with uncertainty bounds. Koizumi said that he would be happy to receive earlier estimates of the R&D-to-GDP ratio and added that policy makers are used to revisions in unemployment and job figures released by the Bureau of Labor Statistics. Therefore, he said, he does not think flash estimates of aggregate R&D figures will lead to confusion. Also, such flash estimates could be produced at a very aggregate level to reduce the impact of sampling error, though that could lead to frustration or confusion among state and local data users who are interested in understanding R&D performance of states. William Bonvillian supported the importance of flash estimates during times of serious cuts in R&D budgets. For example, science and technology policy analysts in government, the private sector, and in academia need to know how the current plans for sequestration may be impacting national R&D performance.

Goldston repeated his warning that there is a trade-off because preliminary estimates might reduce the credibility of the revised figures, which are produced after some delay but are more reliable. He agreed that timely data is always useful, but if the data are not sufficiently credible, it could cause a bigger problem than that of timeliness. In addition, Joel Horowitz noted, using only standard errors as indicators of accuracy, which would be the available metric for data quality, would be insufficient, since they ignore any systematic errors that might be present in the data. He said that a firm's reporting of R&D figures in survey questionnaires is influenced by the tax laws, so a firm may have a motivation to misreport. Christopher Hill agreed that further investigation is necessary to look at systematic errors in NCSES's surveys and how those errors influence the quality of final estimates.

Grueber suggested that, in a way, Battelle's R&D forecast is a preliminary estimate of R&D performance. When it comes to forecasts, the goodness of fit of the forecast model can be determined by how close the forecast is to actual values. Grueber's comparison of his 2011 forecast and Battelle 2011 data differed by $15 billion. The main reason for this difference was attributed to restatements by respondents (firms performing R&D) and updating the *National Patterns* data series. It is his understanding that restatement is sometimes a result of changes in accounting practices. Therefore, forecasting of R&D performance is tricky as users of the forecast expect it to be very close to actual R&D figures, not understanding various reasons for differences. The question is how much of that difference is bearable to the users. This issue will become of concern to NCSES if the agency decides to produce preliminary or flash estimates.

The last two presentations in this session took a very broad view of the STI system. Larson stressed the priority of data analysis instead of the current format of tabular representation of data. NCSES, through its *Info Briefs*, produces a data update and some data analysis, but it is not sufficient to answer the big-picture questions raised by Larson and Goldston. R&D data users focus not only on magnitudes; they also want to understand structural changes, if any, and the channels through which science and technology investments lead to the development of new goods, create more jobs, and otherwise affect the economy. Even though NCSES tries to satisfy (as much as possible) the varied data needs of its broad user community, Hill said it is important to keep in mind that NCSES is a statistical agency, not an analytical agency, and the nature of the agency determines the kinds of data products it produces. NCSES, as a federal statistical agency, designs and conducts surveys to collect data that are relevant to various policy questions. Hill further added that the analytical program of the agency needs to be given importance so that the data products are in line with user community's demands.

National Patterns contains marginal totals that have had broad utility for a variety of users for a long period of time. The Panel on Developing Science, Technology, and Innovation Indicators for the Future in its interim report (National Research Council, 2012a) encouraged NCSES to take steps toward the development of very rich, detailed databases that would support regression models, microsimulation models, and other detailed analyses that would answer specific questions. One of the key drivers of that panel's recommendations is the policy questions raised by Goldston. However, Hill warned, detailed databases contain respondent-level information,[13] and agencies need to be careful about confidentiality issues.

Drilling down to lower levels of geography also brings up additional problems, such as the treatment of interorganizational transfers of R&D funds, as when a firm in one state transfers a major part of an R&D grant to its subsidiary located in another state. When responding to BRDIS, will the firm assign the whole amount to the first location or report the actual split among locations? A similar problem arises with international firms like IBM whose R&D operations are not restricted to a single country. The updated BRDIS contain questions that try to address these two problems (see Chapter 2). Fealing noted that it is a knotty problem given an increase in demand for microlevel data, while statistical agencies need to follow their procedures and categories. Hill expressed concern about whether microlevel

[13]The Public Use Microdata Sample (PUMS) of the Census Bureau is an example of a database that contains respondent-level information. Depending on the variable, the respondent might be a member of a household or a household.

data will provide answers to difficult questions and reiterated the need to begin with good questions.

A question of interest to many researchers is the effect of R&D expenditure at both the regional and national levels. Fealing said that R&D expenditure and funding measures the outputs and inputs of science and engineering enterprise and that measuring effects and spillover of R&D is the next research frontier. Stephanie Shipp added that statistical agencies design surveys to answer specific policy questions, a retrospective approach. She suggested that NCSES takes a more proactive approach by considering administrative records and unstructured data. John Gawalt, Jankowski, and Fealing updated the workshop participants on the progress made by NCSES on its administrative records project (see Chapter 4).

NCSES faces opportunities and challenges in a world that increasingly demands more detailed information. These demands will lead to more pressure on the agency to update its surveys to gather hitherto uncollected information and present the data (tabular and micro) in more informative and usable formats.

4

Statistical Models and Administrative Records as Supplements to Surveys

As part of its charge, the steering committee was asked to consider the following two issues: (1) the appropriateness of the use of specific statistical models to estimate R&D funds going to and spent by nonprofit organizations, and (2) the effects of the timeliness and quality of the census and survey inputs into *National Patterns* in comparison with alternative sources of such information. Relevant to the second issue is the question of whether administrative sources of information, which would generally be more timely, might have comparable quality to that currently collected on the five census and surveys used as inputs into *National Patterns*. This issue is important as it is now generally recognized that response rates for surveys, including government surveys, are in a period of decline.

Although the response rates for the censuses and surveys that supply the inputs to *National Patterns* continue to support very reliable estimates, it remains important for the National Center for Science and Engineering Statistics (NCSES), which produces *National Patterns*, to keep abreast of alternative sources of information in case the response rates to its censuses and surveys experience a decline that threatens the reliability of the estimates. This concern was reflected in the recommendation of a recent National Research Council (2010, p. 60) report:

> Recommendation 4.3: The Division of Science Resources Statistics [the predecessor to NCSES] should initiate work with other federal agencies to develop several demonstration projects to test for the best methods to move to a system based at least partly on administrative records.

The steering committee decided to address this topic by including a workshop session on the quality of the information from STAR METRICS, an ongoing effort to collect administrative records information on R&D funding from a variety of academic institutions.

The first issue was included in the charge because no census or survey on R&D funds from or to nonprofit organizations has been carried out by NCSES since 1996-1997 (see Boroush, 2007). Instead, NCSES has used a statistical model to estimate major components of R&D funds to and from nonprofit organizations. The question for consideration at the workshop was whether this approach results in useful estimates, or that NCSES should consider either re-fielding such a survey or identifying relevant sources of information. An earlier National Research Council (2005, p. 8) report made the following recommendation on this issue: "The panel recommends that another attempt should be made to make a survey-based, independent estimate of the amount of R&D performed in the nonprofit sector." The workshop participants were asked to consider this issue anew.

USING STATISTICAL MODELS TO ESTIMATE R&D FUNDS TO AND FROM NONPROFIT INSTITUTIONS

Nonprofit institutions both provide and receive R&D funds to and from other organizations, including other nonprofit institutions. These funds are often captured by NCSES on its R&D censuses and surveys when the provider or the recipient is not a nonprofit institution. For example, NCSES can estimate the amount of R&D funding that is provided by the federal government to nonprofit institutions from the responses to the Survey of Federal Funds for Research and Development (known as the Federal Funds Survey). Also, from the Higher Education Research and Development Survey (and its predecessor, the Survey of Research and Development Expenditures at Universities and Colleges), NCSES is able to estimate the amount of funds academic institutions received from nonprofit institutions. However, as noted above, NCSES has not fielded a survey that comprehensively covers R&D funds from industry to nonprofit institutions or from nonprofit institutions to other nonprofit institutions for more than 15 years. Given this lack of survey information and given deficiencies in other potential data sources, NCSES has used statistical models to provide estimates of these components of R&D funding. However, these models rely on assumptions that various relationships have not changed appreciably over time, and so they are questionable.

The questions raised by this situation were addressed at the workshop by Michael Cohen of the Committee on National Statistics, who described and critiqued the statistical models currently used by NCSES, and Jeff Alexander of SRI International, who discussed the recent dynamics of nonprofit R&D funding, and alternative administrative sources of information on R&D funds.

Current NCSES Estimation of Nonprofit R&D Funds

Cohen provided a description of the statistical models currently used by NCSES. To produce current estimates of industry funding of R&D performed by nonprofit organizations, NCSES assumes that the annual growth in funding from industry to nonprofit organizations changes in constant proportion to the annual growth in industry-to-industry funding. Since industry-to-industry funding is estimated on an annual basis, this assumption allows inferences about annual growth of funding from industry to nonprofit organizations, which has not been directly estimated since 1997. Estimating the amount of R&D funds provided by a nonprofit institution to another makes use of an analogous ratio relating the relative change in those funds to the percentage change in R&D funds sent from academic institutions to nonprofit institutions.

Although the cost of the current approach is minimal, since it involves no new data collection and only a modest amount of analysis time to recompute the relationship as described above, Cohen said it is reasonable to conclude that the current method is unlikely to provide high-quality estimates, for two reasons. First, as reported by Boroush: "Of the NPOs [nonprofit organizations] surveyed for 1996 and 1997, 59 percent did not respond. . . ." (see p. 49, http://www.nsf.gov/statistics/nsf02303/pdf/sectc.pdf [June 2013]). However, Boroush noted (personal communication) that the respondents accounted for between 80 and 90 percent of total R&D funds. Second, and much more important, the reliance on what must be viewed as a heroic assumption, namely, that the percentage yearly change in one sector of R&D funding divided by the percent yearly change for another sector would remain stable for even a few years, let alone 17 years, is worrisome. It raises the serious concern that the quality of these estimates has seriously deteriorated over time.

Cohen discussed some alternative estimation approaches that might have been considered by NCSES. First, one could posit the constancy of functions other than the ratio of yearly percentage change for one sector to another. Second, within the same basic estimation strategy, there is an alternative technique that derives from the possibility that the stability of the above ratio might be enhanced by partitioning industries into subgroups, each of which might have more homogeneity of the ratio. That is, instead of using a single ratio, multiple ratios would be fit for industries with certain characteristics. Similarly, this approach could be applied to groupings of nonprofit institutions. Third, instead of estimating a single ratio to be used across time, one could view the ratios over time as a time series, which could be smoothed or forecast through the application of a time-series model. Cohen acknowledged that the possible advantages of any of these alternatives cannot be assessed given the absence of a survey for 15 years.

Available and Missing Data on Nonprofit R&D Funding

In addressing the question as to whether the stability assumption that NCSES uses is likely to obtain, Alexander asserted that the nonprofit sector has changed both qualitatively and quantitatively since 1996, with those dynamics likely affecting nonprofit R&D activities. Although the scale of nonprofit R&D activity remains relatively small in comparison with other sectors, it can have a disproportionate impact in specific fields, for example, in biomedical research.

Alexander pointed out that there are nonsurvey sources of information on nonprofit R&D funds, although they provide only partial information toward estimates of total R&D activity:

- For the amounts moving to and from the nonprofit sector, the NCSES Survey of Federal Science and Engineering Support to Universities, Colleges and Nonprofit Institutions provides information on funds to nonprofit institutions from the federal government, the Business R&D and Innovation Survey (BRDIS) provides some information on R&D funds going from industry to nonprofit institutions, and the Higher Education Research and Development (HERD) survey may provide limited information on the R&D funds that universities provide to nonprofit institutions (in the form of pass-through funding).
- For R&D funds provided by nonprofit institutions, BRDIS collects data on funding to industry (though it commingles those funds with government research funding), and HERD provides information on R&D funding from nonprofit institutions to colleges and universities.

The most significant gap, currently not covered by any surveys or censuses, is how much R&D funding goes from nonprofit institutions to other nonprofit institutions. A secondary issue is the quality of BRDIS in accounting for R&D funding between industry and nonprofit institutions.

The Nonprofit Sector in Detail

To better understand the issue, Alexander discussed the nature of nonprofit institutions. The Internal Revenue Service (IRS) code defines a nonprofit institution as follows: "The exempt purposes set forth in section 501(c)(3) are charitable, religious, educational, scientific, literary, testing for public safety, fostering national or international amateur sports competition, and preventing cruelty to children or animals." This definition includes charitable organizations and private foundations. Well-known sponsors of R&D are family foundations (e.g., Packard and Ford), issue-specific foundations (e.g., Susan G. Komen and the American Association for Cancer Research), and corporate foundations (e.g., Intel and Amgen). Well-known recipients of R&D funds are research institutes (e.g., SRI and Battelle), hospitals, and universities and colleges. Some nonprofit institutions are known both as funders and as recipients, including the Howard Hughes Medical Institute and the Monterey Bay Aquarium Research Institute (which is an operating unit of the David and Lucile Packard Foundation). One key statistic relevant to data collection on nonprofit organizations is the high degree of concentration in grantmaking: the largest organizations, which make up less than 1 percent of all nonprofit organizations, account for 59 percent of all nonprofit grant funding.[1]

Alexander said that there is a useful taxonomy, the National Taxonomy for Exempt Entities, which is a classification by organizational mission. There are 26 major groups, with a leading letter that indicates area of primary interest, and each group has two-digit subcategories. Codes are assigned by IRS examiners for tax purposes. Three groups—U20, H30, and V05—are particularly relevant to this discussion. U20 covers organizations that focus broadly on scientific research and inquiry or that engage in interdisciplinary scientific activities (e.g., the Research Triangle Institute); H30 covers organizations that conduct research to improve the prevention, diagnosis, and treatment of cancer (e.g., the Fred Hutchinson Cancer Research Center); and V05 covers organizations whose primary purpose is to carry out research or policy analysis in the social sciences (e.g., the American Enterprise Institute for Public Policy Research).

Alexander then discussed changes in the scale and nature of the nonprofit sector since 1996. First, the number of nonprofit organizations increased from less than 60,000 in 1999 to more than 90,000 in 2008. During the same period, grants by nonprofit organizations increased from about $20 billion to more than $50 billion (in nominal dollars). Between 1998 and 2009, the organizations' assets increased by about 50 percent, including the market correction in 2008-2009. Another major change is that many of what are now the largest private foundations were started quite recently: only two foundations listed among the ten largest funders of science and technology grants in 1998 remained in the top ten in 2010.

[1]Data from National Center for Charitable Statistics (NCCS) data on 501(c)3 private foundations. Available: http://nccsdataweb.urban.org/PubApps/nonprofit-overview-sumRpt.php?v=fin&t=pf&f=0 [March 2013].

Another change is the rise of "venture philanthropy." In the late 1990s, technology entrepreneurs established philanthropic foundations with a different approach to funding, featuring: (1) greater emphasis on outcomes and performance, (2) a closer relationship between the foundation and the grantees, and (3) a strategy of funding a portfolio of "social investments" in the way that venture capital firms fund start-up companies. Alexander added that this rise had also changed philanthropy through the use of multiple initiatives to improve outcome evaluation, efforts to measure grantee satisfaction with the funding process, and a greater focus on innovation in programs and service delivery.

At the same time, however, he said, nonprofit organizations are facing the same pressures as all institutions because of the "great recession." As a result, nonprofit organizations may face structural changes, with the growing use of program-related investments and dedicated venture philanthropic funds. Alexander added that as a result of these recent changes, the funds both provided by and going to nonprofit organizations are more concentrated in a smaller number of organizations, and are awarded using a somewhat different set of objectives. Also, the shift to outcomes-oriented investments may complicate the formulation of questions that attempt to assess the R&D component of grants. Lastly, he said, he expects that nonprofit R&D performers are likely to diversify into new areas of activity.

Alexander said that there are three nonsurvey data sources of R&D funding to and from nonprofit institutions: (1) various federal data repositories, including USASpending.gov, the Federal Audit Clearinghouse, and the Internal Revenue Service Master Business File; (2) third-party data providers, including organizational profile repositories (in particular Guidestar and the NCCS); and (3) nonprofit self-reporting, that is, annual reports and financial statements and IRS Form 990 (for details, see SRI International, 2008). To assess the data in each of these repositories, Alexander used the quality criteria for nonsurvey data sources from *Statistics Canada's Quality Guidelines* (Statistics Canada, 2009). For federal repositories, the major concern is that, except for the IRS, the coverage is poor, since the other sources focus on nonprofit organizations that receive federal grants. For third-party data repositories, the major concern is that detailed information is lacking. For nonprofit self-reporting, the major concerns are coverage and the level of detail, especially since the field for "Nonprofit Program Classification" is not required and is rarely used.

Alexander said that in his opinion, given the various recent dynamics in the sector he noted earlier, there is a strong likelihood that the current *National Patterns*' estimates for nonprofit R&D funding, both funders and performers, are not accurate. Evidence in support of this conclusion is that the most recent (2008) *National Patterns'* estimate of total nonprofit R&D funding was $12.6 billion, but the report on private foundation grant-making by the NCSS was $53.8 billion, and the overall nonprofit R&D funding includes more than private foundation activities. Other evidence comes from the Foundation Center, which estimates that total foundation grant-making has grown much faster over the past 10 years than the nonprofit R&D funding estimate from *National Patterns*. Furthermore, Alexander asserted, current administrative data collections are insufficient to collect consistent and comprehensive information on nonprofit R&D activities because research activities are often embedded in nonresearch programs, and classification systems do not treat R&D funds consistently. Also, nonprofit organizations have little incentive to provide details on their activities, and the data they do provide are delivered in nonmachine-readable formats; in particular, most IRS Form 990s are published online as image pdfs.

However, Alexander noted, some of these data deficiencies are becoming less troublesome. First, more reports are becoming machine readable with e-filing of IRS 990s and greater use of extensible markup language (XML) standards for reporting of financial data. As more nonprofit institutions make more information available online, the data quality is improving. Foundations in particular have launched sectorwide efforts to increase the transparency of their grant-making activities and to establish technical and reporting standards. One example is the Glasspockets initiative, which is building an online, real-time database of grants awarded by major foundations using data feeds from those foundations.[2] Finally, there are some options for applying text analytics to grant project descriptions and IRS Form 990 narratives to assist in classifying R&D activities.

In conclusion, Alexander provided some information that might be useful in designing a new sample survey of R&D funding from and to nonprofit organizations. First, while most nonprofit organizations are either only sponsors or performers of R&D work, there are some that play both roles. The amounts allotted are skewed, in the sense that a relatively small number of nonprofit organizations provide most of the R&D funds, which could make data collection easier. Also, nonprofit funders tend to focus on specific areas of application, which could also facilitate data collection.

E-filing and Survey Possibilities: Discussion

In response to Alexander's presentation, Karen Kafadar asked how the quality of the nonsurvey data sources is assessed. Alexander replied that there is no third party that assesses the data reported. IRS may ask for a clarification or for modifications through an audit. He said that he

[2]For information, see http://www.glasspockets.org [January 2013].

used "quality" to refer to the level of detail that is available in addition to the R&D amounts. Kafadar then suggested that more administrative data might be readily available if more nonprofit organizations change to e-filing, and Alexander agreed. He added that businesses are moving toward use of extensible business reporting language (XBRL), which is a common software standard for financial reporting. However, although the use of XBRL does enhance machine readability, the content may still be less than satisfactory.

Christopher Hill asked how independently organized industrial collaborative R&D efforts—such as the National Center for Manufacturing Sciences, Sematech, and SRC—are categorized. Alexander answered that some are included as nonprofit organizations: for instance, Sematech is a 501(c)(6) organization, and the Electric Power Research Institute is a 501(c)(3).

Joel Horowitz asked why one focuses on this component of R&D spending given that it is dwarfed by that sponsored by the federal government, business and industry, and universities and colleges? Alexander responded that current trends in overall patterns of R&D expenditures, as well as sudden growths or losses, are worth knowing. Yet he acknowledged that if one is making international comparisons, knowing this smallish sector better may not be that important.

Hill asked why there has not been a survey on nonprofit R&D for 15 years. Alexander said that a first reason is the sampling frame might be difficult to generate. There are 1.6 million nonprofit organizations, most of which are church congregations. However, he noted, using a sample that included a certainty stratum of the largest nonprofit organizations would easily collect a very large fraction of total R&D funding for either performers or funders and that the remainder could be sampled using a fairly small sampling rate. Alexander said a second reason is that development of the questionnaire could be complicated given the heterogeneity of the organizations and institutions to be surveyed. He suggested that the most cost-effective approach would be to piggy-back on a survey already fielded by an entity collecting nonprofit data. Fernando Galindo-Rueda suggested the possibility of collecting such information as a byproduct of the data collections carried out by the Bureau of Economic Analysis in producing the national income and product accounts.

STAR METRICS AND VIVO

Interest in STAR METRICS for this workshop reflects current trends of declining response rates for federal censuses and surveys and increasing costs per interview.[3] The cost issue raises the question of whether administrative sources of information on R&D funds might be used in concert with the NCSES surveys to improve the quality of the information on R&D funding. Clearly, whenever a federal R&D grant is provided or whenever an academic institution awards or is awarded a grant, some formal documentation exists about the grant. A compilation of this documentation might serve as a source of information for R&D grants. STAR METRICS is an attempt at such a compilation. One particular possibility the steering committee wanted the workshop participants to consider is to use STAR METRICS information to improve the quality of the census and survey information through editing and imputation techniques. John King of the U.S. Department of Agriculture (USDA) provided a presentation on the current status of STAR METRICS and a related program called VIVO.[4]

Overview

King started by observing that there is a need for common data standards and open platforms to improve our understanding of how science is done. STAR METRICS establishes such data standards to support empirical studies of science impacts. VIVO provides an open platform that helps different scientific institutions meet that standard. His presentation explored these two constructs and how they interact.

STAR METRICS is a platform for the collection and analysis of data on R&D investments that relies on automated harvesting from systems of records. It is intended to provide new applications and tools to meet research needs and policy requirements in the future, and to minimize any administrative burden from structuring this information to support various analytic purposes. Accordingly, STAR METRICS uses a common format consisting of the principal investigator, program information, abstract/proposal, and obligated funds.[5] It includes administrative data about individuals involved in the research, payments to vendors, and subawards, as well as information about any reports and data for analysis from the research. Quarterly updates to STAR METRICS are made by matching through use of grant numbers. Although the initial structure of STAR METRICS was developed

[3]STAR METRICS—Science and Technology for America's Reinvestment: Measuring the Effects of Research on Innovation, Competitiveness, and Science—is a federal collaboration with research institutions; for more information, see https://www.starmetrics.nih.gov [January 2013].

[4]VIVO is an international network for researchers in agricultural fields; for more information, see http://vivoweb.org [January 2013].

[5]A recent paper (Porter, Newman, and Newman, 2012) examined methods to mine the program descriptions in the abstracts and proposals to identify the prominent topical themes addressed in the research. The authors are continuing their work on the subject.

to collect data for federal R&D funds, the same accounting framework is possible for nonfederal research support. King said that the number of institutions currently making up the STAR METRICS community is around 80, but new institutions are joining every month.

A challenge to STAR METRICS is to make the data compatible for many different types of research questions, King said. For instance, there are needs for both extramural and intramural research reports on different aspects of R&D funding. With this data, one can address such research questions as: (1) Does intramural research engage different topics of inquiry? (2) How can R&D portfolios across programs, agencies, or departments be compared? (3) How does scientific discovery differ across settings? and (4) What incentives and rewards do scientists encounter?

King continued with a description of VIVO. VIVO permits USDA researchers to identify colleagues who are carrying out related research, which can accelerate collaboration, and it is also a public-facing expertise locator that portrays the full scope of USDA research. Finally, it provides a connection to other VIVO institutions via its ontologic structure. VIVO thus provides a uniform data structure across USDA's science agencies, it is a source of clean data to document outcomes of intramural science, and it enables sharing of similar information with other federal R&D agencies. A possible application of VIVO is to provide topic modeling using natural language processing, with topic tags provided for each document in the database. It is planned that VIVO will provide expertise locators for review panels and funding announcements.

King expressed the hope that VIVO would support the analysis of research gaps and hotspots, provide the ability to compare research investments to outputs, and support the comparison of projects that are funded with those that are not funded.

Discussion

Alexander first asked how the coding in STAR METRICS distinguishes between scientific and nonscientific grants. Kei Koizumi responded that it was not perfect but that the coding provides a reasonable taxonomy.[6] Alexander asked if they looked at the contracts, and the answer was not yet, but that topic modeling could ultimately be used on the contracts. William Bonvillian asked if the U.S. Department of Defense (DoD) or the National Aeronautics and Space Administration (NASA) are covered in STAR METRICS. King and Koizumi answered that with the exception of

[6] The STAR METRICS algorithm to identify sectors of funds relies heavily on codes from the Catalog of Federal Domestic Assistance (CFDA), which identifies federal agencies and specific program sources of federal funds.

the Army Research Laboratory, DoD and NASA are not covered. The best way to cover them, he said, would be to bring in units that had uniform accounting frameworks, such as NASA. Some of the difficulty stems from the sensitivity of DoD to open up military data. Bonvillian thought that unclassified university research supported by DoD ought to be collectable. He said that given the size of DoD's R&D budget and its role in innovation, it is important to try to bring them on board.

Hill noted, first, that given text mining and related techniques, DoD has a reason not to make everything that is open available for everyone to see. Hill then asked whether, with topic modeling research, the topics are mutually exclusive with regard to the grants and investigators or if the same projects show up under different topics. King responded that grants can indeed show up under multiple topics. Hill pointed out that STAR METRICS is intended ultimately to measure the effects of research on innovation, competitiveness, and science. The science part is done, but what about measuring the effects of innovation and competitiveness? King responded that STAR METRICS could be used to facilitate such research. He mentioned the work of Jason Owens-Smith at the University of Michigan, who is examining the labor market outcomes of the grants that trained graduate students. Hill said that the number of jobs was not the same thing as innovation. King responded that they are also looking at tracking the collaborations among principal investigators through STAR METRICS and Bibliometrics to see whether certain patterns of collaboration end up producing different kinds of science. David Newman then asked: What are the incentives of universities to participate in STAR METRICS? King responded that they get a better view of their own institution. They get back quarterly reports that are helpful for understanding what research is being carried out. Also, the researchers can find out who else is doing relevant work at their institution. The last topic raised was coverage. Bonvillian asked: Of the roughly 150 leading research universities, how many are in STAR METRICS? King answered between one and two dozen.

STAR METRICS for Edit and Imputation

Cohen's presentation considered using STAR METRICS to improve *National Patterns*. He began by noting that STAR METRICS is unlikely to cover industrial R&D statistics in the near future. It is also clear from King's presentation that its coverage for the frame of the HERD survey is also unlikely to approach the level necessary for use in support of *National Patterns* in the near future. Therefore, STAR METRICS will not soon be able to replace the censuses and surveys that are used as input to *National Patterns*. However, if STAR METRICS values are subject to less measurement error than the analogous responses to the censuses and surveys, these alternative values might be useful for improving the quality of the census and survey data through editing or imputation.

Either assumption—that censuses or surveys could provide preferred data to STAR METRICS or vice versa—can find support. Census and survey responses might be preferable because administrative records systems often contain errors as a result of matching problems and other data linkage errors. But STAR METRICS values might be preferred to survey and census responses since the actual documentation of the grant is used for data entry, which may reduce various sources of measurement error, such as recall error.

For the purposes of his presentation, Cohen said he assumed that the administrative sources were of superior quality in comparison with the information received from census and survey respondents, though he acknowledged that the assumption may ultimately prove false. Cohen noted that Chris Pece of NCSES was currently involved in an effort to determine the circumstances under which the census and survey data were and were not preferable to STAR METRICS data through a match study.

One way in which STAR METRICS information could be used to improve the survey and census responses is through the use of editing routines. Assume, for example, that there is a census response and a STAR METRICS value for a response and that they differ by more than *p* percent, or that one amount is nonzero and the other is zero. In such situations, it would seem beneficial to contact the respondent to ask for a clarification. The likely result would be an improved dataset. Of course, investigating each alert of a potential discrepancy could be labor intensive, and respondents often do not like to be questioned, especially if the survey or census response was correct. So, if one wanted to implement such a procedure, one would want to keep such callbacks to a minimum without greatly increasing the number of true discrepancies that were missed. In order to do that, one would need to develop a much better understanding of the distribution of differences that arise in situations in which either the survey or census response was correct, or was in error, and similarly for the STAR METRICS value, in order to develop an effective editing routine.

A second possibility would be to use STAR METRICS values for imputation. If one has both a census (or survey) response and a STAR METRICS value and the discrepancy between them results in a failed edit, and if for some reason one cannot resolve the discrepancy by contacting the respondent, an imputation model could provide a correction. For instance, one possibility would be to assume that the errors in census (or survey) responses and the errors in STAR METRICS were independent and normally distributed. Then an imputation routine could be based on a linear combination of the two values weighted by their relative precision. But their error distributions could be substantially different from this assumption. For example, the errors might be such that values are "changed to zero" with some probability (which could happen, for example, by attributing the wrong identification number to a grant). Correctly diagnosing such errors and providing good imputations for the census or survey responses would require a very different imputation model than one that would be effective in the first posited situation.

In what could serve as a first step toward the development of imputation and editing routines, NCSES is undertaking an exploratory data analysis of the differences between STAR METRICS and census values. But even after this research is completed, Cohen noted, it may still be a very challenging task to design an effective editing or imputation routine. He noted that this kind of matching study is currently being conducted at the Census Bureau for a wide range of survey and census responses because of the increased availability of administrative records in a variety of contexts.[7]

In addition to editing and imputation when census and STAR METRICS values are both available, Cohen suggested some additional though somewhat speculative uses for STAR METRICS data that might serve to improve the responses to NCSES surveys and censuses in the future. For example, if one is missing the census (or survey) response for a quantity for which the STAR METRICS value is available, the STAR METRICS value could be used as a surrogate for the survey response. An important hypothetical example might be values for nonprofit R&D, if STAR METRICS in the future included a substantial fraction of nonprofit R&D activity. Absent a new census or survey of R&D funding to and from nonprofit institutions, one would be concerned that such STAR METRICS data were not validated for this purpose. However, given the lack of a recent survey and the likely poor performance of the current estimation approach, such an approach might still be an improvement in the data in *National Patterns*.

In addition to using the STAR METRICS values only as survey surrogates, in situations in which data have been collected recently for a large number of census and STAR METRICS pairs, using such paired data in addition to the analogous STAR METRICS value for the missing census response might enable one to develop a model-based imputation for missing census responses that would be preferable to using the analogous STAR METRICS value as a surrogate.

Cohen added that, more broadly, even in situations in which the census response is available, again assuming that STAR METRICS data are shown to be more reliable, and further assuming that one discovered that STAR

[7] For instance, the most recent Federal Committee on Statistical Methodology Research Conference, held in January 2012, included a presentation entitled "Evaluating Job Data in the Redesigned SIPP Using Administrative Records" by Martha Stinson of the Census Bureau.

METRICS values had a strong relationship (including over time) with the census (or survey) values, one might model this relationship and then use such a model to "adjust" census responses. In this case, one is in effect estimating the census response using the combination of census and STAR METRICS responses for all institutions (possibly using not only data for the current time period, but also historical data). However, it is difficult to imagine that one would find such a stable relationship because the census responses are very likely to be correct, and so it is not easy to find an imputation model that would improve on an observed census or survey value. In any case, use of such a model would require a comprehensive validation effort, which would be very expensive to carry out. In addition, since STAR METRICS is a voluntary program, one should also be concerned that the institutions that choose not to participate are different than those for which the model was developed.

5

Small-Area Estimation

With the notable exception of the estimation of nonprofit R&D funding amounts, the National Center for Science and Engineering Statistics (NCSES) primarily uses standard survey estimates—that is, direct survey-weighted totals and ratios—in its tabulations for *National Patterns*. Design-based survey regression estimators, although they can be more accurate in many survey applications, are often not used for lack of exploratory studies to develop good survey predictors (whose totals are known or measured accurately by other instruments). In relation to consideration of more sophisticated estimation techniques, the charge to the steering committee included the issue of the responsiveness of the information content to user's needs.

The workshop covered a set of techniques that could provide, for instance, estimates for state-level R&D funds for specific types of industries. This is a type of tabulation that NCSES believes its users would be very interested in obtaining. In addition, the subject of the distinction between measurement error and definitional vagueness, which is related to data quality, was raised during the discussion period; a summary of that discussion is included as a short section at the end of this chapter.

OVERVIEW

Julie Gershunskaya of the Bureau of Labor Statistics presented a survey of current methods for small-area estimation that have been found useful in various federal statistical applications. Such techniques have the potential to produce R&D statistics on more detailed domains for inclusion in future

National Patterns reports. Currently, the *National Patterns* reports tabulate statistics on R&D funding primarily at the national level, but there are also state-level tabulations for some major categories of funders and performers for the current year. In addition, tabulations of industrial R&D funding are also available for about 80 separate North American Industrial Classification System (NAICS) codes, down to three digits of detail.[1] These efforts to provide information for subnational domains are commended. Kei Koizumi noted earlier in the workshop that many users would benefit from the publication of statistics on R&D funding for more detailed domains: possibilities include providing R&D funding for substate geographic levels or for domains defined by states crossed by type of industry. There may also be interest in providing future tabulations for particular categories of colleges and universities.

A small area is defined as a domain of interest for which the sample size is insufficient to make direct sample-based estimates of adequate precision. These "small areas" in the context of R&D can be geographic entities, industrial types, sociodemographic groups, or intersections of geography, industry, or demography. Small-area estimation methods are techniques that can be used, when the sample size is inadequate, to produce reliable estimates by using various additional sources of information from other domains or time periods. However, such methods do rely on various assumptions about how that information links to the information from the domain of interest.

Gershunskaya said at the outset that the best strategy to avoid reliance on small-area estimation is to provide for sufficiently reliable direct estimates for the domains of interest at the sample design stage. However, it is typical for surveys carried out by federal statistical agencies to have insufficient sample sizes to support estimates for small domains requested by the user communities. Hence, the need for small-area estimates is widespread.

Gershunskaya differentiated between direct and indirect estimates. Direct estimates use the values on the variable of interest from only the sample units for the domain and time period of interest. They are usually unbiased or nearly so, but due to limited sample size, they can be unreliable. Indirect estimates "borrow strength" outside the domain or time period (or both) of interest and so are based on assumptions, either implicitly or explicitly. As a result of their use of external information, indirect estimates can have smaller variances than direct estimates, but they can be biased if the assumptions on which they are based are not valid. The objective therefore is to try to find an estimator with substantially reduced variance but with only slightly increased bias.

[1]For 2007 data, see http://www.nsf.gov/statistics/nsf11301/pdf/tab58.pdf [January 2013].

DIRECT ESTIMATORS

Gershunskaya first reviewed the basic Horvitz-Thompson estimator and then discussed several modifications to it.

Horvitz-Thompson

Introducing some notation, let the quantity of interest be denoted by Y_d for domain d of the population. In considering the application of these methods to R&D statistics, domains could be defined by states or by industries with a certain set of NAICS codes. Each sampled unit j has an associated sample weight, denoted w_j, which is equal to the inverse of a unit's probability of being selected.[2] (The rough interpretation is that the weight corresponds to the number of population units represented by each sampled unit.)

The Horvitz-Thompson estimator of Y_d is

$$\sum_{j \in s_d} w_j y_j ,$$

where y_j is the measurement of interest for sample unit j, and s_d denotes the set of sampled units in domain d. The Horvitz-Thompson estimator may be unreliable, especially for small domains. To address this, there are various alternative direct estimators that may out-perform the Horvitz-Thompson estimator, especially when auxiliary data are available.

Ratio Estimators

To discuss these estimators, additional notation is needed. Let y_j denote the measurement of interest for sample unit j, let x_j denote auxiliary data for sample unit j (assumed univariate to start), and let X_d be the known population total for domain d, from administrative or census data. (Note that the dependence of both y_j and x_j on domain d is not explicitly indicated in the notation to keep things more readable.) In the case of R&D statistics, y_j could be the R&D expenditure for company j, x_j could be the total payroll for company j, and X_d could be the true population total payroll in a particular state. Then the ratio estimator, using sample data, is given by

[2]In practice, survey weights are almost never design weights in the sense of being inverse selection probabilities; nonresponse adjustment or imputation (or both) change their properties (see, e.g., Särndal and Lundström, 2005).

$$\hat{Y}_d^{(R)} = X_d \hat{B}_d \text{, where } \hat{B}_d = \frac{\hat{Y}_d^{HT}}{\hat{X}_d^{HT}},$$

where $\hat{Y}_d^{HT}$ and $\hat{X}_d^{HT}$ are the Horvitz-Thompson estimators of the respective population totals. If there is a substantial correlation between R&D expenditure and payroll size, the ratio estimator may provide a marked improvement over the Horvitz-Thompson estimator.

A particular case of the ratio estimator is given for the situation where x_j equals 1 if j is in the d^{th} domain and equals zero otherwise, which is referred to as the post-stratified estimator. In this case, letting N_d be the number of population units in the domain (assumed to be known), and letting

$$\hat{N}_d^{(HT)} = \sum_{j \in s_d} w_j$$

be the sample-based estimate of N_d, the post-stratified estimator can be written as

$$\hat{Y}_d^{(PS)} = N_d \frac{\hat{Y}_d^{(HT)}}{\hat{N}_d^{(HT)}}.$$

The post-stratified estimator has improved performance in comparison with the Horvitz-Thompson estimator. However, when the domain sample size is small, the post-stratified estimator can still perform poorly.

Generalized Regression Estimator

The ratio estimator can be expressed as a special case of the Generalized Regression (GREG) estimator:

$$\hat{Y}_d^{(GREG)} = \hat{Y}_d^{(HT)} + \left(X_d - \hat{X}_d^{(HT)}\right)^T \hat{B}_d,$$

where:

X_d is a vector of known population totals for domain d,

$\hat{X}_d^{(HT)}$ is a vector of Horvitz-Thompson estimates of X_d,

$\hat{Y}_d^{(HT)}$ is a Horvitz-Thompson estimate of Y_d, and

$\hat{B}_d$ is a vector of coefficients (derived from the sample using a particular formula).

This estimator also belongs to a variety called calibration estimators, as the second term here "corrects" (or "calibrates") the Horvitz-Thompson estimator for Y using known population totals for X.

Note that the estimator for B_d is based on sample data. When the sample size is small, this estimate may be unstable. To address this, one can pool the data over domains to produce a single $\hat{B}$. The resulting *modified direct estimator*, known as the survey regression estimator, is expressed as follows:

$$\hat{Y}_d^{(SR)} = \hat{Y}_d^{(HT)} + \left(X_d - \hat{X}_d^{(HT)}\right)^T \hat{B}.$$

Gershunskaya illustrated how this estimator might be applied to NCSES R&D data. Let X_{im} be the known population payroll in industry-type i and state m, $\hat{X}_{im}^{(HT)}$ be the Horvitz-Thompson estimate of payroll in industry-type i and state m, $\hat{X}_i^{(HT)}$ be the Horvitz-Thompson estimate of payroll, national total for industry-type i, and $\hat{Y}_i^{(HT)}$ be the Horvitz-Thompson estimate of R&D funds, national total for industry-type i. Then, one can compute

$$\hat{B}_i = \frac{\hat{Y}_i^{(HT)}}{\hat{X}_i^{(HT)}}$$

using national data for industry i in the survey regression estimator to estimate

$$\hat{Y}_{im}^{(SR)} = \hat{Y}_{im}^{(HT)} + \left(X_{im} - \hat{X}_{im}^{(HT)}\right)^T \hat{B}_i.$$

Gershunskaya pointed out that, although $\hat{B}$ in the survey regression estimator is based on a larger sample, the effective sample size still equals the domain sample size. To see why that is so, one can rewrite the survey regression estimator as

$$\hat{Y}_d^{(SR)} = X_d\hat{B} + \sum_{j \in s_d} w_j \left(y_j - x_j\hat{B}\right),$$

which shows that the survey regression estimator is a sum of the fitted values from a regression model based on predictors from the domain of interest, and it has a bias correction from weighting the residuals again from a regression using data only from that domain. Therefore, the efficiency of the survey regression estimator depends on the variability of the residuals and on the domain sample size.

INDIRECT ESTIMATORS

Gershunskaya then moved to a description of indirect estimators. As she noted earlier, direct sample-based estimators are unbiased (or nearly so) but they may have unacceptably large variances. To overcome this problem, certain assumptions about similarity or relationships between areas or time periods (or both) are made, and these assumptions allow one to use more sample data, thus "borrowing strength." Her first example of an indirect estimator was the synthetic estimator, which is a sample-based estimator for which the parameters estimated from larger (or combined) domains or from other time periods are applied to a small area. She then discussed the structure-preserving estimator, known as SPREE, and composite estimators.

Synthetic Estimator

To describe synthetic estimation, Gerhsusnkaya began with the usual direct estimate of the sample domain mean from a simple random sample, namely:

$$\bar{y}_d = \frac{1}{n_d} \sum_{j \in s_d} y_j \ .$$

Unfortunately, this estimator can be unreliable if the sample size in the domain is small, so one would want to use the data from the other domains to improve its reliability. One obvious candidate, assuming that means are constant over domains, would be the global average over all domains. The resulting estimator,

$$\bar{y}_d = \frac{1}{n} \sum_{j \in s} y_j \ ,$$

is an example of the synthetic estimator. It is much more stable, but it is very likely to be substantially biased because the assumption of a common mean across domains will rarely hold. If there are auxiliary variables, a more realistic assumption than the assumption of a common mean would be to assume, for example, a common regression slope across domains. Consider again the survey regression estimator:

$$\hat{Y}_d^{(SR)} = X_d\hat{B} + \sum_{j\in s_d} w_j\left(y_j - x_j\hat{B}\right).$$

This estimator can be depicted as survey regression equals model plus bias correction. The "model" part of the survey regression estimator turns out to be a synthetic estimator,

$$\hat{Y}_d^{(Syn)} = X_d\hat{B}.$$

To better understand synthetic estimation, consider an R&D example. A synthetic estimator of R&D expenditure in industry type *i* and state *m* is

$$\hat{Y}_{im}^{(Syn)} = X_{im}\hat{B}_i,$$

where $\hat{B}_i = \dfrac{\hat{Y}_i^{(HT)}}{\hat{X}_i^{(HT)}}$ and it is assumed that the common ratio $\hat{B}_i$ of R&D to total payroll holds across all states in industry type *i*.

NCSES has already used a similar approach to produce a Survey of Industrial R&D state estimator, which is described in Slanta and Mulrow (2004). For her example, Gershunskaya said, R&D for state *m* is estimated as

$$\hat{Y}_m = Y_{m,s} + \hat{Y}_{m,c},$$

where

$$Y_{m,s} = \sum_{j\in s} y_{m,j}$$

is the observed sample total for R&D in state *m*, and $\hat{Y}_{m,c}$ is a prediction of the nonsampled part of the population for R&D in state *m*, which is computed as

$$\hat{Y}_{m,c} = \sum_{i=1}^{I} R_{im}\hat{Y}_{i,c}$$

where R_{im} is the ratio of payroll in state *m* to national payroll total for industry *i*, and

$$\hat{Y}_{i,c} = \sum_{j\in s}\left(w_j - 1\right)y_{i,j}$$

is a prediction for the nonsampled part of R&D in industry type *i*. This approach relies on the assumption that in each industry type *i*, R&D is distributed among states proportionately to each state's total payroll.

Gershunskaya compared the state estimator from Slanta and Mulrow (2004) with the synthetic estimator based on a common industry slope. For simplicity, Gershunskaya considered the estimator for the whole population, rather than for only the nonsampled part. The Slanta-Mulrow (SM) estimator can then be expressed as

$$\hat{Y}_m^{(SM)} = \sum_{i=1}^{I} \frac{X_{im}}{X_i} \hat{Y}_i^{(HT)},$$

and the common industry slope estimator can be expressed as

$$\hat{Y}_m^{(CIS)} = \sum_{i=1}^{I} X_{im} \frac{\hat{Y}_i^{(HT)}}{\hat{X}_i^{(HT)}}.$$

Both estimators are synthetic estimators and are based on similar assumptions. Notice that in the denominators, the Slanta-Mulrow estimator uses the population total X_i, and the common industry slope estimator uses the Horvitz-Thompson estimator $\hat{X}_i^{(HT)}$ of the population total X_i. It might be worth evaluating these two competing estimators using BRDIS data. If indeed R&D is correlated with payroll, the common industry slope estimator may prove to be preferable.

SPREE

Another synthetic estimator is SPREE, the structure preserving estimator. It is based on a two-dimensional table of estimates, with elements C_{im}, with one dimension indexed by *i* and running from 1 to *I* (e.g., type of industry) and the other dimension indexed by *m* and running from 1 to *M* (e.g., state). The C_{im} here represents the total of R&D funds for all industries of a certain type in a given state. SPREE assumes that initial estimates of individual cell totals, C_{im}, are available from a previous census or from administrative data, though as such they are possibly substantially biased. This approach also assumes that the sample from a current survey is large enough so that one can obtain direct sample-based estimates for the marginal totals, denoted $\hat{Y}_i$ and $\hat{Y}_m$. The goal is to estimate the amount of R&D funding for each of the individual cells by updating them to be consistent with the marginal totals. Iterative proportional fitting (also known as raking) is a procedure that adjusts the cell totals C_{im} so that the modified table conforms to the new marginal estimates. The revised cell totals are the new small-area estimates.

The implicit assumption is that the relative structure of the table is constant since the last census, that is,

$$\frac{\frac{C_{ij}}{C_{kj}}}{\frac{C_{il}}{C_{kl}}} = \frac{\frac{Y_{ij}}{Y_{kj}}}{\frac{Y_{il}}{Y_{kl}}}$$

for any combination of indices *i*, *j*, *k*, and *l*.

In summary, Gershunskaya said, direct estimators are unbiased and should be used when the sample size is sufficient to produce reliable estimates. However, with small samples they have large variances. Synthetic estimators, in contrast, have smaller variances but they are usually based on strong assumptions, and therefore may be badly biased if their assumptions do not hold.

Composite Estimators

Gershunskaya then turned to another type of indirect estimator, composite estimators. They are convex combinations of direct and synthetic estimators, which provide a compromise between bias and variance. They can be expressed as follows:

$$\hat{Y}_d^{(C)} = \nu_d \hat{Y}_d^{(Direct)} + \left(1 - \nu_d\right) \hat{Y}_d^{(Model)}.$$

The central question in using them is how one should choose the weights ν_d. One possible approach is to define weights on the basis of sample coverage in the given area, e.g., selecting ν_d proportional to $\hat{N}_d / N_d$. However, this method fails to account for variation of the variable of interest in the area. A second possibility is to use weights that minimize the mean squared error of the resulting estimator. This second method depends on potentially unreliable estimates of the mean squared error of composite parts.

Methods Based on Explicit Models

In contrast to these approaches that are based on implicit models, the final general category of estimators described by Gershunskaya covers methods based on explicit models. Explicitly stated modeling assumptions allow for the application of standard statistical methods for model selection, model evaluation, the estimation of model parameters, and the production of measures of uncertainty (e.g., confidence intervals, mean squared error) under the assumed model. Methods based on explicit models constitute the core of modern small-area methods.

The most popular small-area methods are based on either the linear mixed model (for continuous variables) or the generalized linear mixed model (for binary or count data). Two types of models are commonly used, area-level and unit-level models. An area-level model (with assumptions pertaining to the aggregate area level) is applied when only area-level auxiliary data are available (rather than auxiliary data for individual units). In this case, direct sample-based estimates play the role of individual data points in the model, with their sampling variances assumed to be known. Generally, area-level models are easier to apply than the unit-level models. One benefit from the application of these models is that they usually take into account the sample design.[3]

Unit-level models (with the assumptions based on relationships between individual respondents) require different and more detailed information (which is why they are seldom used by statistical agencies) and generally rely on assumptions of independence of units, assumptions that are often violated in clustered survey designs. But if the assumptions for unit-level models are tenable and the unit-level data are available, one would want to use them in place of area-level aggregated models for reasons of efficiency. However, some complications can arise when trying to account for the sample design.

Fay-Herriot Small-Area Model

Fay and Herriot (1979) introduced an area-level model in the context of the estimation of per capita income for small places. The authors used the following set of auxiliary variables: county level per capita income, the value of owner-occupied housing, and the average adjusted gross income per exemption. Fay-Herriot models are often represented using two-level model assumptions, the sampling model and the linking model. The sampling model states that the direct sample estimator estimates the true population parameter without bias and with a certain (sampling) error. The linking model makes certain assumptions (e.g., linear regression relationship) about the true underlying values.

In the Fay-Herriot model, the sample-based estimate is

$$\hat{Y}_d^{(Direct)} = \theta_d + \varepsilon_d \,,$$

[3]However, some areas may not have any sample. If areas are selected into the sample with unequal probabilities related to the true area means, bias may occur as a result.

that is, the sum of an expected value plus an error term with zero mean and with its variance equal to the sampling variance of the direct sample estimate. The linking model for the mean can be written as

$$\theta_d = X_d^T \beta + \nu_d .$$

This equation indicates that the mean of the sample estimate is expressed as a linear combination of the auxiliary variables $\left(X_d^T \beta\right)$ plus a model-error, ν_d, having mean zero and a constant variance, with the model error independent of the sampling error. The entire model can then be expressed as

$$\hat{Y}_d^{(direct)} = X_d^T \beta + \nu_d + \varepsilon_d ,$$

which is a linear mixed model since it has both fixed and random effects. Under this model, the best unbiased linear estimator (in a certain well-defined sense) for θ_d has a composite form, as follows:

$$\hat{\theta}_d = \gamma_d \hat{Y}_d^{(Direct)} + \left(1-\gamma_d\right) X_d^T \hat{\beta} ,$$

where

$$\gamma_d = \frac{A}{A + V_d^{(Direct)}} ,$$

A is the variance of the random term in the linking model, and $V_d^{(Direct)}$ is the sampling variance, which is assumed known. The above composite form shows that the direct estimates are shrunk toward the synthetic part, where the smaller A is (i.e., the better the linking model explains the underlying relationship), the more weight goes to the synthetic (i.e., model-based) part. Similarly, areas with estimates with larger sampling variances also have more weight allotted to the synthetic part.

R&D Example

Gershunskaya then provided an example to show how one might produce small-area estimates of R&D funds for small domains defined by states and industry types. Let $\hat{Y}_{im}^{(Direct)}$ be a direct sample-based estimator for R&D in industry i and state m from BRDIS. The direct sample estimator provides unbiased measurement of the unobserved truth θ_{im}, with some random error:

$$\hat{Y}_{im}^{(Direct)} = \theta_{im} + \varepsilon_{im} \text{ (sampling model).}$$

The assumption is that ignoring an error term, the state-level R&D funds in industry type i are proportional to the state's total payroll, which can be expressed as

$$\theta_{im} = X_{im}B_i + v_{im} \text{ (linking model).}$$

The resulting small-area estimator can be written as

$$\hat{\theta}_{im} = X_{im}\hat{B}_i + \gamma_{im}\left(\hat{Y}_{im}^{(Direct)} - X_{im}\hat{B}_i\right), \text{ where } \gamma_{im} = \frac{\hat{A}_i}{\hat{A}_i + V_{im}^{(Direct)}}.$$

Estimation of B_i and A_i are straightforward from the data. (A cautionary note: this application differs from the formal Fay-Herriot model since the variances of ε_{im} must be estimated and can be inaccurate if they are based on small sample sizes.)

Unit-Level Small-Area Modeling

An example of a unit-level model is a small-area model of areas planted with corn and soybeans for 12 Iowa counties (Battese, Harter, and Fuller, 1988). The survey data consisted of Y_{dj}, the number of hectares of corn (or soybeans) per segment j in county d. The auxiliary variables, collected by satellite, were $x_{1,dj}$, the number of pixels planted with corn per segment j in county d, and $x_{2,dj}$, the number of pixels planted with soybean per segment j in county d. The model considered in the paper is called the nested-error regression:

$$Y_{dj} = \beta_0 + \beta_1 x_{1,dj} + \beta_2 x_{2,dj} + v_d + \varepsilon_{dj},$$

where the error terms are independent. The resulting small-area estimator is

$$\hat{\theta}_d = \gamma_d \bar{y}_d + \left(1 - \gamma_d\right)\left(\hat{\beta}_0 + \hat{\beta}_1 \bar{x}_{1d} + \hat{\beta}_2 \bar{x}_{2d}\right),$$

where

$$\gamma_d = \frac{\sigma_v^2}{\sigma_v^2 + \sigma_e^2 / n_d}.$$

Note that the larger the sample size of an area, the more relative weight is placed on the sample part of the weighted average. The regression coefficients and the error variances are easily estimated from the data. Both the Fay-Herriot and the Battese, Fuller, and Harter models are examples of linear mixed models, Gershunkaya noted.

Smoothing Over Time

None of the models presented so far examined the potential from use of the dependent variable collected from previous time periods. This is extremely relevant for R&D statistics, Gershunskaya said, since many of the surveys and censuses used as inputs for *National Patterns* have a relatively long, stable, historical series, often going back to the 1950s. As an example of a small-area spatial-temporal model, Gershunskaya described the results in Rao and Yu (1994). For areas $d = 1, \ldots, D$ and time periods $t = 1, \ldots, T$, assume that

$$\hat{Y}_{dt}^{(Direct)} = X_{dt}^{T}\beta + v_{d} + u_{dt} + \varepsilon_{dt} \,,$$

where the u_{dt} are random error terms that follow a first-order autoregressive process. In this case, a good small-area estimator (for the current period) is a weighted sum of the synthetic estimator for the current period and model residuals from the previous time periods, namely,

$$\hat{\theta}_{dT} = \gamma_{dT}\hat{Y}_{dT}^{(Direct)} + \left(1-\gamma_{dT}\right)X_{dT}^{T}\hat{\beta} + \sum_{t=1}^{T-1}\gamma_{dt}\left(\hat{Y}_{dt}^{(Direct)} - X_{dt}^{T}\hat{\beta}\right).$$

Modifications for Discrete Dependent Variables

Gershunskaya then briefly discussed models for discrete dependent variables. The most common case is when y_d is a binary variable. Assume that the quantity of interest is the small-area proportion

$$P_d = N_d^{-1}\sum_{j\varepsilon d} y_{dj} \,.$$

Then one can formulate an area-level Fay-Herriot-type model using direct sample-based estimates of proportions. However, the area-level approach has shortcomings, one of which is that some areas may have no sample units reporting R&D and thus will be dropped from the model. A unit-level generalized linear mixed model may be more efficient in this case. Assume that y_{dj} is 1 with probability p_{dj} and 0 with probability $1 - p_{dj}$; then the standard model in this situation has the following form:

$$\log\left(\frac{p_{dj}}{1-p_{dj}}\right) = x_{dj}^T\beta + v_d .$$

Implementing Small-Area Modeling for *National Patterns*

Gershunskaya then indicated how NCSES could develop explicit small-area models using the *National Patterns* datasets. She first considered a unit-level model scenario. Assume that wages, employment, and possibly other covariates are obtained from administrative data for all businesses in the target population. Using sample data, one could establish a relationship between R&D funding and auxiliary variables by fitting the parameters of some explicit model. One could then apply the results of this model fitting to the prediction of R&D in the nonsampled part of the above models. However, because there is no explicit question on state-by-industry R&D in the BRDIS questionnaire, a proxy for it would have to be derived. (Although possible, it would currently be a laborious effort.) In such modeling, it would be important to account for the sample design in the variance estimation, which is a serious complication.

The second scenario proposed by Gershunskaya was for an area-level model. Here a current design-based ratio or regression estimator (or other area-level predictor(s), e.g., "true" population values available from an administrative file) could be used in the synthetic part of the composite estimator. It would also be useful to consider alternative direct estimators of R&D that could be used in the area-level model, Gershunskaya said, and she outlined a few possibilities of improved direct estimators (based on the theory developed by Sverchkov and Pfeffermann, 2004). Let $\delta_{m,j}$ be 1 if company j reports R&D in state m, and 0 otherwise. If one does not have auxiliary information, an alternative direct sample estimator is

$$\hat{Y}_m = \sum_{j\in s} y_{m,j} + \left(N_m - n_m\right)\frac{\sum_{j\in s}\left(w_j - 1\right)y_{m,j}}{\sum_{j\in s}\delta_{m,j}\left(w_j - 1\right)} .$$

As an analogue of the ratio estimator, using company's payroll x_j or some other auxiliary variable (possibly payroll per employee), a modified form of the previous alternative direct sample estimator can be defined as

$$\hat{Y}_m = \sum_{j \in s} y_{m,j} + X_{m,c} \frac{\sum_{j \in s} (w_j - 1) y_{m,j}}{\sum_{j \in s} \delta_{m,j} (w_j - 1) x_j},$$

where $X_{m,c}$ is the total payroll in the nonsampled portion of state m. Finally, as an analogue of the modified direct estimator,

$$\hat{Y}_m = \sum_{j \in s} y_{m,j} + \sum_{i=1}^{I} X_{im,c} \hat{B}_i + (N_m - n_m) \hat{M}_{m,c},$$

where

$$\hat{B}_i = \frac{\sum_{j \in s} y_{i,j}}{\sum_{j \in s} \delta_{i,j} x_j}, \; where\; \delta_{i,j} = \left\{ \begin{array}{c} 1 \; if\ company\ j\ reports\ R\&D\ in\ industry\ i \\ 0\ otherwise \end{array} \right\}$$

$$\hat{M}_{m,c} = \frac{\sum_{j \in s} \delta_{m,j} (w_j - 1) \left(y_{m,j} - \sum_{i=1}^{I} x_{im,j} \hat{B}_i \right)}{\sum_{j \in s} \delta_{m,j} (w_j - 1)}.$$

Final Considerations and Discussion

Gershunskaya concluded her review of small-area estimation methods with a set of important considerations:

- It is important to plan for estimation for domains of interest at the design stage to ensure that one has direct estimates of some reliability to start off.
- Finding a set of good auxiliary variables is crucial for success in small-area modeling.
- Small-area estimation methods are based on assumptions, and therefore evaluation of the resulting estimates is vital.
- Using a statistical model supports a systematic approach for a given problem: (a) the need for explicitly stated assumptions, (b) the need for model selection and checking, and (c) the production of measures of uncertainty.
- It is important to account for the sample design (unequal probabilities of selection and clustering effects) in the model formulation and fitting.

Joel Horowitz pointed out that these models have a long history, and there are methodologies that have been developed that avoid the assumption of linearity or proportionality and that can accommodate estimation errors in the predictors. Gershunskaya agreed that there were nonparametric models that had such properties. She said that her presentation was already detailed and therefore some complicated issues could not be included. Eric Slud added that the sample survey context made some of this particular application more difficult than in the literature that Horowitz was referring to. Slud added that the key issue in applying these techniques is finding predictive covariates. Often, one is restricted to synthetic variables, often measured in more aggregated domains.

Another topic that emerged during the floor discussion was whether there were likely to be productive predictors available in this context. Slud said that clearly there were opportunities to use synthetic variables by using information at higher levels of aggregation. However, the availability of useful predictors at the respondent level was less clear and would be known only by subject-matter researchers conducting some exploratory data analysis.

John Jankowski said that one of NCSES's highest areas of concern in terms of data presentation is the state and subnational distribution of R&D activity. He added that the business sector is the one for which this is most relevant. He said that a small firm in Massaschusetts sampled in BRDIS could have a weight of 250 so the resulting direct small-area estimates would likely be unreliable, but he noted that the Slanta and Mulrow (2004) paper was successful in reducing the magnitude of that problem. However, it could not address the small-area distribution by industrial category because in the Survey of Industrial R&D for the distribution of R&D by industry sector the funds were just assigned to the major industry category. Now, however, BRDIS has the entire distribution of R&D by industry sector and so there is a great deal more potential for the use of small-area estimation. Jankowski added that BRDIS also provides the geographic distribution of such funds. Even though geography and industrial sector are not simultaneously available, he said that it might now be possible to produce such estimates through some hard work, though it is not certain. Jankowski added as things stand now, if there is a large R&D-performing company that is 51 percent in one category and 49 percent in another, 100 percent would be assigned to the first category, and users would notice that. New technology gives us a chance to better distribute those funds to industrial categories.

Christopher Hill was concerned that if the National Science Foundation provided small-area estimates, there would be situations in which experts in R&D funding would know that the estimates are incorrect because they have local information. Slud responded that this is the case for every set of small-area estimates. When such situations occur, they should be seen as opportunities to improve either the quality of the input data, the form of the model, or the variables included in the model. Many participants noted that model validation is an important part of the application of these techniques. Jankowski added that it would be unclear the form in which such estimates would be made publicly available.

Slud pointed out that prior to application of this methodology, it is important to explore how sensitive the results are to the model assumptions, which depends on the relative size of the sampling errors to the others that one might be able to quantify. Karen Kafadar pointed out that one advantage with this methodology is that since you get standard errors for your estimates, you can compare your estimates with ground truth and know whether they are or are not consistent.

MEASUREMENT ERROR OR DEFINITIONAL VAGUENESS

As noted above, an issue that arose during the workshop concerned the need to better understand sources of error underlying NCSES survey and census responses. Survey data are subject to sampling error and nonsampling error, with nonsampling error often decomposed into nonresponse error and measurement error. As is almost always the case for survey estimates, NCSES does not have a complete understanding of the magnitude of nonsampling error. Several participants suggested that it would be beneficial for NCSES to investigate this topic, possibly through greater use of reinterviews or comparison of survey and census responses with administrative records (see section on STAR METRICS in Chapter 4).

In particular, several participants pointed out that it would be important to distinguish between true measurement error, that is, when the total R&D funding level is misreported, and differences in interpretation, for example, in distinguishing between what is applied research and what is development. It was suggested this issue could be addressed through the use of focus groups and other forms of cognitive research. Or a subsampling study could be carried out in which answers subject to possible definitional vagueness could be followed up and resolved. However, several participants acknowledged that such a study would be expensive and labor intensive.

6

Presentation of Information in *National Patterns*

Although the content and methods for *National Patterns* were the primary topics for the steering committee and workshop, there was also interest in whether the current presentation of the information, generally through use of tables, could be enhanced either through the use of different tabular presentations or through the use of maps. Thus, one workshop session was devoted to the presentation of information in *National Patterns*, led by Daniel Carr of George Mason University. He discussed the work he has done for federal agencies, such as the Bureau of Labor Statistics and the National Cancer Institute, and how spatial and longitudinal data could be displayed in a more informative way for *National Patterns* users.

BASIC PRINCIPLES AND COGNITIVE SCIENCE

Carr began by offering his four design principles for statistical graphics, two focusing on content and two on presentation:

1. Feature meaningful, accurate comparisons.
2. Provide a rich context for interpretation by including reference values, related variables, temporal or spatial context, and an assessment of uncertainty or quality.
3. Strive for a simple appearance.
4. Attract and engage people by providing added-value appearance, interactive choices with guidance, and feedback, educational pathways, and opportunities to contribute.

He added that statistical graphics design involves compromise because these four principles can be in conflict and because designs must also address the constraints of the media and audience.

The design of statistical graphics should consider human cognitive limitations and strengths, he noted. Often overlooked limitations include the universal forms of blindness called inattentional and change blindness. To demonstrate inattentional blindness, he described a person-swap scenario. In this scenario, Person A is giving directions to Person B, but during a moment of distraction for Person A, Person C takes the place of Person B. In an experiment designed by Derren Brown,[1] Person A continues giving directions without noticing that the person asking for directions is not the same. Carr said that the big bottleneck in human visual processing is visual working memory, which can handle only from one to three (simple) visual objects (see Ware, 2008). Visual objects not immediately needed are not retained and may not be stored in long-term memory.

In addition to visual memory, verbal reasoning is needed to work with numbers and think about quantitative graphics. Human working auditory memory consists of a 2-second sound loop, which is also limiting in terms of presenting information. Carr suggested that although there is a lot to learn from cognitive science, enough is already known to improve statistical graphics designs and the accompanying text.

Although there are many barriers to change, some guidance is relatively easy to put to work. Having too much information to process easily in one chunk makes a plot appear complex, whether or not it is. For example a graphics panel showing more than four lines (time series) appears complex. Perceptually grouping lines into panels that have four or fewer lines per panel simplifies the plot appearance.

Cognitive strengths include adjustable visual queries, parallel processing of visual and auditory systems, and for some tasks the ability to adapt and learn. This ranges from the priming of neurons to respond faster when a similar pattern appears to training based on the reduction of the cognitive effort associated with learning new tasks.

Carr said that design guidance is applicable to both statistical tables and graphics, and he offered ideas for redesign of a *National Patterns* table: see Table 6-1. One design feature is the use of black dots to call attention to total and subtotal columns. People can tune their vision to scan for black dots, just as they can tune their vision to scan for red items in the room. As described by Ware (2008), the things that pop out on a page are the things for which people can use their top-down control to tune for low-level visual processing. Among the several other changes is the use of light gray lines in the background to provide smaller perceptual groups of rows to support

[1]See http:/www.youtube.com/watch?v=vBPG_OBgTWg [March 2013].

TABLE 6-1 Proposed Presentation of R&D Expenditures by Performing Sector and Source of Funds Over Time

Dollar Units: Current Millions

Years: 1953–2008

Table 2. US Basic Research Expenditures
By Performance Sectors and Funding Sources

	All Performers	Federal	Industry			Industry FFRDCs	U&C						U&C FFRDCs	Other nonprofit organizations				Nonprofit FFRDCs
	All Sources	Federal ●	Total ●	Federal	Industry	Total ●	Total ●	Federal	Other Government	Industry	U&C	Other Nonprofit	Total ●	Total ●	Federal	Industry	nonProfit	Total ●
1953	460	102	151	19	132	NA	123	82	7	13	6	16	36	48	27	9	12	NA
1954	509	96	166	23	143	NA	148	97	10	15	8	18	44	55	31	11	13	NA
1955	579	98	189	27	162	NA	180	117	14	17	12	21	50	63	36	13	14	NA
1956	718	114	253	37	216	NA	220	143	19	20	15	24	58	74	42	15	17	NA
1957	814	124	271	41	230	NA	261	167	25	23	20	27	72	87	49	15	23	NA
1958	944	149	295	43	252	NA	312	202	31	24	24	31	85	103	59	16	28	NA
1959	1,087	165	320	72	248	NA	388	263	38	24	28	36	95	120	72	18	30	NA
1960	1,286	184	376	79	297	NA	485	341	45	25	33	41	106	136	85	21	30	NA
1961	1,512	230	395	81	314	NA	598	432	54	25	40	48	126	164	105	22	37	NA
1962	1,824	252	488	143	345	NA	737	546	64	25	48	55	148	200	130	24	46	NA
1963	2,115	285	522	147	375	NA	909	689	75	25	58	63	175	225	150	25	50	NA
1964	2,396	339	507	123	384	42	1,071	824	84	25	70	68	200	238	166	25	47	NA
1965	2,664	375	563	157	406	29	1,221	944	94	27	86	70	218	260	179	29	52	NA
1966	2,930	410	593	142	451	31	1,380	1,066	104	29	106	75	239	278	188	32	58	NA
1967	3,168	434	595	168	427	34	1,554	1,188	114	34	136	83	263	289	194	34	61	NA
1968	3,376	482	607	145	462	35	1,681	1,265	131	38	156	91	276	296	196	37	63	NA
1969	3,491	545	581	123	458	37	1,754	1,288	153	40	171	103	272	302	192	43	67	NA
1970	3,594	562	566	122	444	36	1,855	1,323	179	43	196	115	265	311	195	44	72	NA
1971	3,720	581	557	101	456	33	1,968	1,385	194	50	214	127	252	329	207	45	77	NA
1972	3,850	603	554	91	463	39	2,038	1,437	195	55	216	134	270	347	216	47	84	NA
1973	4,099	652	595	96	499	36	2,103	1,489	196	59	223	137	343	371	232	49	90	NA
1974	4,511	715	650	114	536	49	2,282	1,609	204	66	250	153	415	401	245	54	102	NA
1975	4,875	760	677	104	573	53	2,480	1,768	212	72	264	164	476	430	255	59	116	NA
1976	5,373	850	750	116	634	69	2,675	1,924	218	75	283	175	556	474	278	65	131	NA
1977	6,008	943	836	135	701	75	2,967	2,114	232	89	334	198	667	521	301	72	148	NA
1978	6,959	1,044	941	156	785	94	3,376	2,399	260	107	398	213	906	598	351	79	168	NA
1979	7,836	1,112	1,054	161	893	104	3,828	2,719	286	128	466	229	1,050	689	413	87	190	NA
1980	8,745	1,212	1,205	170	1,035	120	4,315	3,061	307	156	544	248	1,167	726	416	95	215	NA
1981	9,658	1,343	1,477	164	1,313	137	4,737	3,331	338	183	615	269	1,284	671	324	105	243	9
1982	10,651	1,522	1,776	253	1,523	128	5,091	3,475	368	215	716	317	1,366	759	369	115	275	9

SOURCE: Daniel Carr's re-expression of National Patterns of R&D Resources: 2009 Data Update. NSF 12-321.

local focus and more accurate horizontal scanning. The grouping in units of five is a compromise, being more than the suggested perceptual groups of four. However, thinking about years in units of 10 is convenient and use of groups of 5 is compatible with this.

AVAILABLE TOOLS

Carr added that interactive tables have a history and a future. Historically, Table Lens software has provided many interactive features (see Rao and Card, 1994). Now, variable selection, row and column reordering, and focusing tools are increasingly common, and statistical methods are more available to support the making of comparisons in a table context.

Although tables remain important for some tasks, there are merits to using statistical graphics for many discovery, analysis, and communication tasks. Carr showed a linked micromap that uses a graphical user interface for variable selection and uses statistical graphics to represent estimates and confidence intervals for both the primary variable of interest and related variables.[2] The graphics include reference values and color-linked micromaps that show spatial patterns. The interactive applet provides "drill-down" capabilities from states to counties, and supports reordering rows and columns.

The website for the *Nation's Report Card*[3] provides instructive example tables related to state achievement (student averages) on standardized tests. These tables foster statistical comparisons in two ways. First, the variables available for interactive selection include differences, such as differences between male and female average scores for each state. The 95 percent confidence intervals of such differences for each state can draw attention to states whose intervals do not include zero. Such differences are unlikely to be due to random variation and so are of interest in investigating disparities.

Second, the interactive table on the National Center for Education Statistics website supports selection of a reference value to use in making comparisons. For example, selecting the national public value adds a table column that shows states in one of three categories: those with confidence intervals below, including, or above the national public reference value. People find it easy to think in terms of three ordered categories, such as small, medium, and large, and so they also find it easy to think of states as belonging to one of three categories. This column of state categories can be

[2]The example shown at the workshop is available at: http://statecancerprofiles.cancer.gov/micromaps, a database maintained by the National Cancer Institute.

[3]This website of the National Center for Education Statistics is available at: http://nces.ed.gov/nationsreportcard/states [January 2013].

represented in a map, where three colors can encode each state's category. An alternative encoding shows three panels of maps with one panel for each class. States are then highlighted in the panel indicating their category.

Figure 6-1 shows the extension of this encoding approach to representing three variables: 8th grade reading, 4th grade mathematics, and 8th grade mathematics achievement scores. The center map shows Illinois in gray so Illinois's 8th grade reading achievement score is similar to the national public achievement score. Since the plot highlights Illinois in the middle row and middle column, the 4th and 8th grade mathematics average scores are also similar to the national public averages scores. States that have all average score confidence intervals below the national public scores are purple and appear in the lower left panel. States that have all average score confidence intervals above the national public are green and appear in the top right panel. This comparative micromap design shows both the association among these three variables and spatial patterns.

Carr noted that there are new designs based on confidence intervals that are emerging from exploratory graphic designs for showing three variables in a geospatial context. He showed additional education examples that he created using dynamic Java software called CCmaps (conditioned choropleth maps), which serves as an exploratory tool. It also uses a 3 × 3 grid of maps with highlighted states. One key difference is that three-class

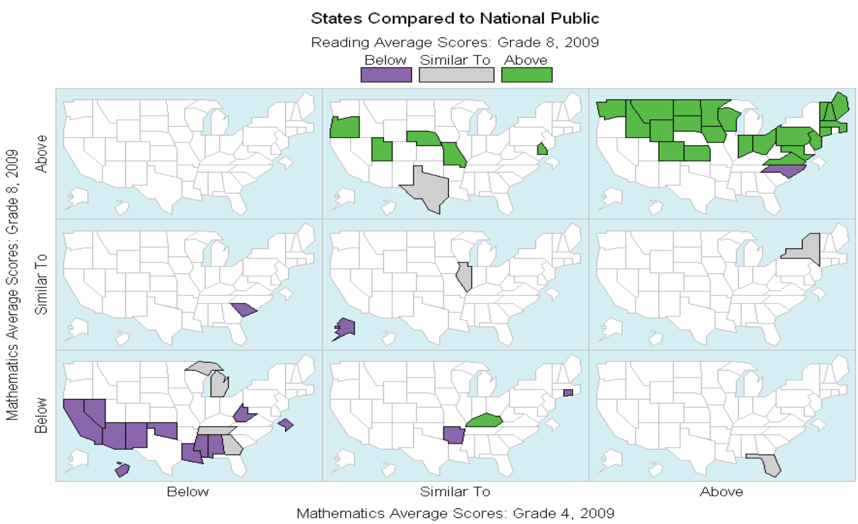


FIGURE 6-1 State educational achievement scores for three variables: An example of micromaps.
SOURCE: Carr (2012).

"sliders"—buttons that allow for continuous changing of class definition—are positioned above, to the right and below the grid of maps and provide control of the partitioning of states to low, middle, and high classes for each of three interactively selected variables. The software also provides dynamic statistical feedback, guidance about slider settings, and alternative views. Carr and Pickle (2010) describe these capabilities and also address other design issues, such as simplifying map boundaries for visualization purposes.

International interest in *National Patterns* is a reason, Carr said, to make world maps to show spatial-temporal patterns for many nations. He noted, however, that world maps typically have visibility problems for small nations and that for some data the big difference between neighboring nations makes it more difficult to see and learn spatial patterns.

As an alternative to world maps, Carr showed examples from Gapminder.[4] He mentioned that Gapminder's animated bubble scatter-plots help visualize time series for two variables. Although animation poses some visual and cognitive problems, they can be partially addressed.

Carr said that one can juxtapose a few state maps to show all the state class memberships and changes over time. He showed a temporal change maps design that displays state expenditures of R&D funding relative to the gross domestic product for just four of the yearly maps: see Figure 6-2. In this design, an analyst uses a dynamic three-class slider below the maps to put states into low, middle, and high classes based on their values. The blue, gray, and red colors in the middle row of maps indicate the class memberships over time. However, even when studying two maps that are in sight, such as the 1993 and 1998 maps, it is hard to find all the class changes. When people's eyes jump from map to map in movements called saccades, they are effectively blind, and their change detectors are reset. People can only remember a little area in focal attention long enough to make a comparison across maps.

In general, careful comparison of two juxtaposed similar images requires tedious back-and-forth comparisons of small corresponding areas. People see the new focal location, but the usual feedback about change in the large visual field is absent. Change blindness is the phenomena of not noticing many changes because one's visual change detectors have been reset. Explicitly showing the class changes, as in Figure 6-2, addresses the change blindness problem. Specifically, the top row of maps shows all the states that changed to a higher category in their new color which is either gray or red. The bottom row shows all the states that changed to a lower category in their new color which is either gray or blue.

Carr and Pickle (2010) describe a variety of comparative micromaps. Their examples include maps that can be indexed by such variables as age

[4]For information, see http://www.gapminder.org [January 2013].

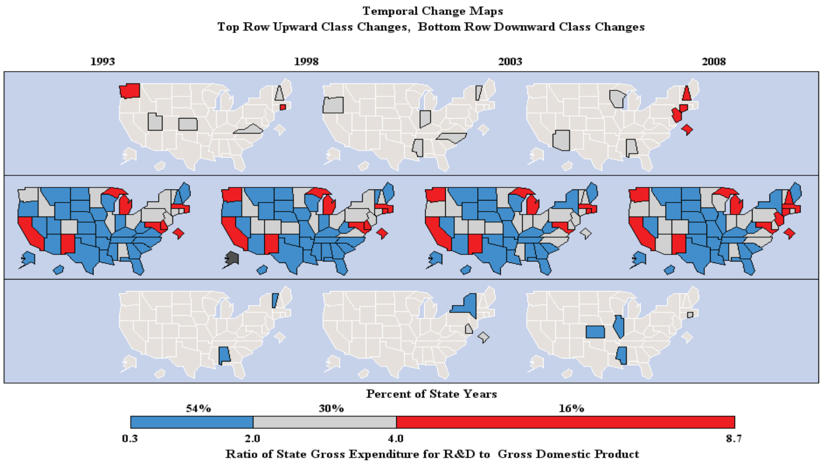


FIGURE 6-2 Ratio of state gross R&D expenditures to GDP, as illustrated by temporal change maps.
SOURCE: Carr (2012).

group, sex, and race as well as by time. Carr noted that Java software called TCmaps (temporal change maps) now supports dynamic interaction with such graphics and includes some new designs: for an example, see Figure 6-3. This example addresses percent changes in black and white populations for 4 years in Louisiana parishes. Hurricanes Katrina and Rita occurred after the 2005 census and the impact was quite different for the two populations. The example shows linked filter sliders on the left that are set to highlight parishes with changes of more than 1.78 percent. The highlighted parishes appear in the second and fourth rows of maps. The first and fifth rows are change maps that show parishes that changed from unselected to selected using color-filled polygons. Parishes that changed from selected to unselected appear with colored outlines. The maps in the center row are called cross maps. These represent parish class membership in a 2 × 2 matrix indicating selected or not selected for the two populations. Parishes in the background were not selected. Yellow indicates parishes that have percent changes of more than 1.78 for both black and white populations.

Carr said that the above examples suggest a variety of graphics designs that NCSES could produce. He commended NCSES on many of the graphical displays in the 2012 *Science and Engineering Indicator Digest*, the 2011 *Women, Minorities, and Person with Disabilities in Science and Engineering*, the 2010 *Key Science and Engineering Indicator Digest*, and the 2009 *Doctorate Recipients from U.S. Universities*. He noted the excellent use of linked graphics and text, the attention given to many details, and high print

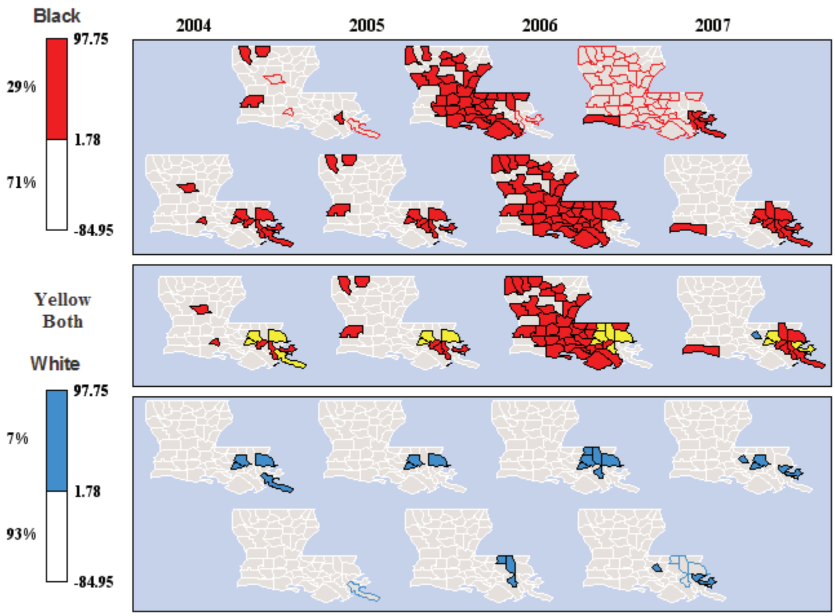


FIGURE 6-3 Comparing populations in Louisiana parishes, 2004-2007: Illustration of use of micromaps with linked highlighting sliders and subset cross plots.
NOTES: The top panel shows changes in the black population; the middle panel is a cross map, and the bottom panel shows changes in the white population.
SOURCES: Carr (2012) and Zhang (2012).

quality that provided a value-added appearance. He observed some style variations across the documents and suggested that variety can be good.

As an example of possible improvement, he offered a different approach for the legend in a figure from *Women, Minorities, and Persons with Disabilities in Science and Engineering* that puts the legend in empty space to increase plot resolution: see Figures 6-4a and 6-4b. His variant is designed to use the same space and include the same content. Changes include putting the legend above the plot, changing the y-axis label style, and adding grid line labels on the right where people are likely to assess the values. But, he said, he is not sure whether the result is easier or harder for readers. His concern was the complex appearance due to too many overplotted lines in the same panel and too many color and label links. Thus, his alternate uses web graphics space to reduce the complex appearance.

In conclusion, Carr pointed out that web graphics can open many doors. They can allow for user variable selection, variable transformations, focusing tools, full color, the opportunity to comment and contribute, and

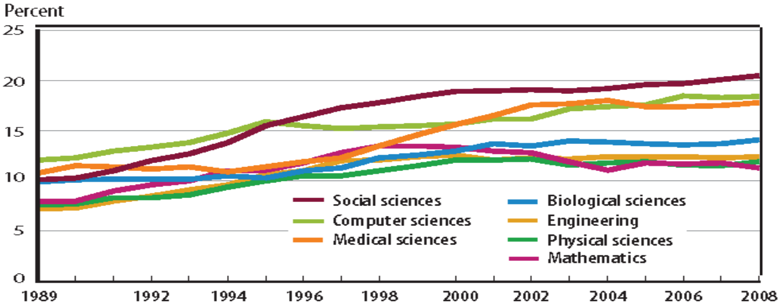


FIGURE 6-4a Time plot of percent minorities with science and engineering bachelor's degrees, 1989-2008: Original presentation.
NOTE: Data are not available for 1999.
SOURCE: 2011 *Women, Minorities, and Persons with Disabilities in Science and Engineering*.

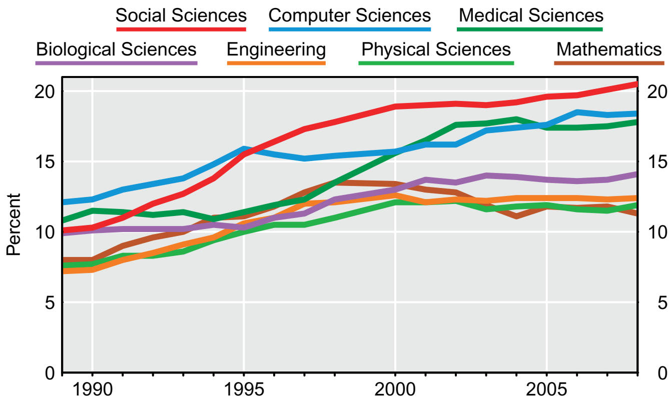


FIGURE 6-4b Time plot of percent minorities science and engineering bachelor's degrees, 1989-2008: Alternative design.
NOTE: Data are not available for 1999.
SOURCE: Carr (2012).

better access to data and graphics. In addition to his book with Linda Pickle and Rao and Card (1994), Carr also suggested that people look at Ware (2008) and Kosslyn, Thompson, and Ganis (2006).[5]

[5]Linked micromaps can be found at http://www.gis.cancer.gov/tools/micromaps [March 2013] and conditioned micromaps can be found at http://www.math.yorku.ca/SCS/sasmac/ccmap.html [March 2013]. Carr also mentioned dynamically conditioned chloropeth maps, which are described at http://dgrc.org/dgo2004/disc/demos/tuesdemos/carr.pdf [March 2013].

DISCUSSION

Chris Hill asked what the programming demands are on implementing such graphical tools. Carr responded that it requires knowledge of Java, which does take some expertise. Michael Cohen asked whether there are concerns regarding disclosure avoidance. Carr answered that the suppression that would be used for a comparable tabular presentation is used prior to implementation of these graphics. Karen Kafadar asked whether anyone had carried out usability studies as a result of the implementation of such graphical tools. Carr said that users often wanted structure that went against Carr's principles but were closer to what users were accustomed to. Two examples are the need to provide context up front, and the need to rank things from top to bottom, rather than have the best be the middle of the map.

Kafadar wondered whether there was feedback from the general user community as to utility. Carr didn't think so. John Jankowski wondered how the variables used to define subgroups were determined. Carr responded that the selection of variables was due to collaboration between the subject-matter experts and himself. Cohen said that there is now some interest in R&D patterns both over time and subnationally. These are the types of tools that could be used to display that, correct? Carr agreed that state structure over time could be represented. Kafadar pointed out that *National Patterns* had 168 variables: Would it be hard to select the right subset for each response of interest? Carr said that nowadays searching a file with that number of variables was relatively easy.

References

Battese, G.E., Harter, R.M., and Fuller, W.A. (1988). An error components model for prediction of county crop areas using survey and satellite data. *Journal of the American Statistical Association*, *83*, 28-36.

Boroush, M. (2007). *National Patterns of R&D Resources*. 2006 Methodology Report, Division of Science Resources Statistics. Arlington, VA: National Science Foundation.

Boroush, M. (2012). *National Patterns of R&D Resources: Key Aspects of Data, Methods and Reports*. Paper presented at the Workshop on Future Directions for the NSF National Patterns of Research and Development Reports, National Research Council, Washington, DC. Available: http://sites.nationalacademies.org/DBASSE/CNSTAT/DBASSE_082214 [April 2013].

Branscomb, L.M., and Auerswald, P.E. (2002). *Between Invention and Innovation: An Analysis of Funding for Early-Stage Technology Development*. NIST GCR 02-841. Gaithersburg, MD: National Institute of Standards and Technology. Available: http://www.atp.nist.gov/eao/gcr02-841/contents.htm [January 2013].

Carr, D.B. (2012). *Improving Communications*. Paper presented at the Workshop on Future Directions for the NSF National Patterns of Research and Development Reports, National Research Council, Washington, DC. Available: http://sites.nationalacademies.org/DBASSE/CNSTAT/CurrentProjects/DBASSE_072008#.UO7qX4cupQQ [January 2013].

Carr, D.B., and Pickle, L.W. (2010). *Visualizing Data Patterns with Micromaps*. Boca Raton, FL: CRC Press.

Fay, R., and Herriot, R. (1979). Estimates of income for small places: An application of James-Stein procedures to census data. *Journal of the American Statistical Association, 74*, 341-353.

Ford, G.S., Koutsky, T.M., and Spiwak, L.J. (2007). *A Valley of Death in the Innovation Sequence: An Economic Investigation*. Discussion paper, Phoenix Center for Advanced Legal and Economic Public Policy Studies, prepared for the Commerce Technology Administration, U.S. Department of Commerce. (Study Contract No. SB1341-05-2-0023 administered by KT Consulting, Inc.) Available: http://www.phoenix-center.org/Valley_of_Death_Final.pdf [January 2013].

Foster, R.N. (1986). *Innovation: The Attacker's Advantage*. London, England: Macmillan.

Foster, R.N., and Kaplan, S. (2000). *Creative Destruction: Why Companies That Are Built to Last Underperform the Market—And How to Successfully Transform Them*. New York: Currency.

Galinda-Rueda, F. (2012). *Advances in International Comparability of National Patterns Data and Reports*. Paper presented at the Workshop on Future Directions for the NSF National Patterns of Research and Development Reports, National Research Council, Washington, DC. Available: http://sites.nationalacademies.org/DBASSE/CNSTAT/CurrentProjects/DBASSE_072008#.UO7qX4cupQQ [January 2013].

Godin, B. (2008). *The Making of Statistical Standards: The OECD and the Frascati Manual, 1962-2002*. Project on the History and Sociology of STI Statistics. Working paper no. 39. Available: http://www.csiic.ca/PDF/Godin_39.pdf [January 2013].

Grueber, M., and Studt, T. (2011). 2012 global R&D funding forecast. *Battelle and R&D Magazine*. Available: http://battelle.org/docs/default-document-library/2012_global_forecast.pdf?sfvrsn=2 [February 2013].

Jaffe, A.B., and Trajtenberg, M. (2005). *Patents, Citations, and Innovations: A Window on the Knowledge Economy*. Cambridge, MA: MIT Press.

Jaruzelski, B., Loehr, J., and Dehoff, K. (2011). The Global Innovation 1000: Why culture is key. *strategy+business,65*(winter). Available: http://www.booz.com/media/uploads/BoozCo-Global-Innovation-1000-2011-Culture-Key.pdf [February 2013].

Kosslyn, S.M., Thompson, W.L., and Ganis, G. (2006). *The Case for Mental Imagery*. New York: Oxford University Press.

Mowery, D. (2012). *An Academic User's Perspective on National Patterns*. Paper presented at the Workshop on Future Directions for the NSF National Patterns of Research and Development Reports, National Research Council, Washington, DC. Available: http://sites.nationalacademies.org/DBASSE/CNSTAT/DBASSE_082214 [April 2013].

National Economic Council. (2011). *A Strategy for American Innovation: Driving Towards Sustainable Growth and Quality Jobs*. Available: http://www.whitehouse.gov/administration/eop/nec/StrategyforAmericanInnovation [January 2013].

National Research Council. (2005). *Measuring Research and Development Expenditures in the U.S. Economy.* Panel on Research and Development Statistics at the National Science Foundation. L.J. Brown, T.J. Plewes, and M.A. Gerstein, Eds. Committee on National Statistics, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Research Council. (2010). *Data on Federal Research and Development Investments: A Pathway to Modernization*. Panel on Modernizing the Infrastructure of the National Science Foundation Federal Funds Survey. Committee on National Statistics, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Research Council. (2012a). *Improving Measures of Science, Technology, and Innovation: Interim Report*. Panel on Developing Science, Technology, and Innovation Indicators for the Future. R.E. Litan, A.W. Wyckoff, and K.H. Fealing, Eds. Committee on National Statistics, Division of Behavioral and Social Sciences and Education, and Board on Science, Technology, and Economic Policy, Division of Policy and Global Affairs. Washington, DC: The National Academies Press.

National Research Council. (2012b). *Rising to the National Challenge: U.S. Innovation Policy for the Global Economy.* Committee on Comparative National Innovation Policies: Best Practice for the 21st Century. C.W. Wessner and A.W. Wolff, Eds. Board on Science, Technology, and Economic Policy, Division of Policy and Global Affairs. Washington, DC: The National Academies Press.

National Science Board. (2010). *Key Science and Engineering Indicators: 2010 Digest.* Arlington, VA: National Science Foundation.

National Science Board. (2012). *Science and Engineering Indicators 2012*. NSB 12-01. Arlington VA: National Science Foundation. Available: http://www.nsf.gov/statistics/seind12/c4/c4s8.htm [January 2013].

National Science Foundation. (2012a). *2011 Business Research & Development and Innovation Survey Form BRDI-1*. National Center for Science and Engineering Statistics. Available: http://www.nsf.gov/statistics/srvyindustry/about/brdis/surveys/srvybrdis_2011.pdf [January 2013].

National Science Foundation. (2012b). *Federal Funds for Research and Development: Fiscal Years 2009-11*. Detailed Statistical Tables NSF 12-318. National Center for Science and Engineering Statistics. Available: http://www.nsf.gov/statistics/nsf12318/ [January 2013].

National Science Foundation. (2012c). *National Patterns of R&D Resources: 2009 Data Update*. NSF 12-321. National Center for Science and Engineering Statistics. Available: http://www.nsf.gov/statistics/nsf12321 [January 2013].

National Science Foundation. (2012d). *U.S. R&D Spending Suffered a Rare Decline in 2009 but Outpaced the Overall Economy.* National Center for Science and Engineering Statistics. NSF 12-310. Available: http://www.nsf.gov/statistics/infbrief/nsf12310 [January 2013].

National Science Foundation. (2012e). *ARRA Funding Raises R&D Expenditures within Federally Funded R&D Centers 11% to $16.8 Billion in FY 2010.* NSF 12-315. National Center for Science and Engineering Statistics. Available: http://www.nsf.gov/statistics/infbrief/nsf12315 [March 2013]

National Science Foundation. (2013). *U.S. R&D Spending Resumes Growth in 2010 and 2011 but Still Lags Behind the Pace of Expansion of the National Economy*. NSF 13-313. Available: http://www.nsf.gov/statistics/infbrief/nsf13313 [January 2013].

National Science Foundation and National Center for Science and Engineering Statistics. (2005). *National Patterns of R&D Resources: 2003*. NSF 05-308. Arlington, VA. Available: http://www.nsf.gov/statistics/nsf05308 [April 2013].

Obama, B. (2009). *Remarks by President Barack Obama at the National Academy of Sciences.* Presentation at the 146th annual meeting, April 27, Washington, DC. Available: http://www.pnas.org/content/106/24/9539.full.pdf+html [January 2013].

OECD. (2011). *Main Science and Technology Indicators Database*. Available: http://dx.doi.org/10.1787/888932485196 [February 2013].

Porter, A.L., Newman, D., and Newman, N.C. (2012). *Text Mining to Identify Topical Emergence: Case Study on Management of Technology*. 17th paper presented at the International Conference on Science and Technology Indicators, Montreal, Quebec, Canada. Technology Policy and Assessment Center, Georgia Tech, Atlanta, GA.

Rao, J.N.K., and Yu, M. (1994). Small-area estimation by combining time-series and cross-sectional data. *Canadian Journal of Statistics, 22*, 511-528.

Rao, R., and Card, S.K. (1994). The table lens: Merging graphical and symbolic representations in an interactive focus + context visualization for tabular information. *Human Factors in Computing Systems CHI '94 Conference Proceedings,* 318-322.

Romer, P.M. (1986). Increasing returns and long run growth. *Journal of Political Economy, 5*, 1002-1073.

Romer, P.M. (1990). Endogenous technical change. *Journal of Political Economy, 98*(5), S71-S102.

Rosenberg, N. (1994). *Exploring the Black Box: Technology, Economics, and History.* New York: Cambridge University Press.

Särndal, C.E., and Lundström, S. (2005). *Estimation in Surveys with Nonresponse.* Wiley Series in Survey Methodology. New York: John Wiley & Sons.

Schaaper, M. (October 2012). *Measuring R&D Personnel*. Paper presented at the National Workshop on Science, Technology and Innovation Statistics, Abu Dhabi, UAE. Available: http://www.uis.unesco.org/StatisticalCapacityBuilding/WorkshopDocuments/STWorkshopdox/UAE2012/MeasuringRDPersonnel.ppt [February 2013].

Slanta, J., and Mulrow, J.M. (2004). A hybrid estimation approach to state-level estimates in the Survey of Industrial Research and Development. *Proceedings of the American Statistical Association Section on Survey Research Methods*. Available: http://www.amstat.org/sections/srms/Proceedings/y2004/files/Jsm2004-000230.pdf [April 2013].

SRI International. (2008). *Task Order 34: Feasibility of Data Collection on Nonprofit Sector Funding and Performance of S&E R&D*. Arlington, VA: SRI International.

Statistics Canada. (1998). *Statistics Canada Quality Guidelines*. Third Edition, Methodology Branch. Available: http://190.25.231.249/aplicativos/sen/aym_document/aym_biblioteca/Documento%20de%20soporte/Statistics%20Canada%20Quality%20Guidelines,%20Third%20Edition%20-%20October%201998.pdf [April 2013].

Statistics Canada. (2009). *Statistics Canada Quality Guidelines*. Fifth Edition, Catalogue no. 12-539-X. Available: http://www.statcan.gc.ca/pub/12-539-x/12-539-x2009001-eng.pdf [June 2013].

Sverchkov, M., and Pfeffermann, D. (2004). Prediction of finite population totals based on the sample distribution. *Survey Methodology, 30*(1), 79-92.

Ware, C. (2008). *Visual Thinking: for Design*. San Francisco, CA: Morgan Kaufman.

Zhang, C. (2012). *Interfaces and Visual Analytics for Visualizing Spatio-Temporal Data with Micromaps*. Ph.D. Dissertation, George Mason University, Fairfax, VA.

Appendix A

Acronyms and Abbreviations

ANBERD	analytical business enterprise research and development
ARRA	American Recovery and Reinvestment Act of 2009
BEA	Bureau of Economic Analysis
BRDIS	Business R&D and Innovation Survey
CCmaps	conditioned cloropleth maps
CFDA	Catalog of Federal Domestic Assistance
CNSTAT	Committee on National Statistics
DoD	U.S. Department of Defense
EU	European Union
FFRDCs	federally funded research and development centers
FTE	full-time equivalent
GBAORD	government budget appropriations or outlays on R&D
GDP	gross domestic product
GERD	gross domestic expenditure on R&D
GOVERD	government expenditure on R&D
GREG	generalized regression estimator
HERD	Higher Education Research and Development Survey

IRIS	Industrial Research and Development Information System
IRS	Internal Revenue Service
MSTI	main science and technology indicators database
NAICS	North American Industry Classification System
NASA	National Aeronautics and Space Administration
NCSES	National Center for Science and Engineering Statistics
NCSS	National Center for Charitable Statistics
NRC	National Research Council
NSF	National Science Foundation
ONS	Office of National Statistics
OSTP	White House Office of Science and Technology Policy
R&D	research and development
RDS	research and development statistics
SEC	Security and Exchange Commission
SESTAT	Scientists and Engineers Statistical Data System
SIPP	Survey of Income and Program Participation
SIRD	Survey of Industrial R&D
SPREE	structure preserving estimator
STAR METRICS	Science and Technology for America's Reinvestment: Measuring the Effects of Research on Innovation, Competitiveness and Science
STI	science, technology, and innovation
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	U.S. Department of Agriculture
WebCASPAR	Integrated Science and Engineering Resource Data System
XBRL	extensible business reporting language
XML	extensible markup language

Appendix B

Workshop Agenda and Participants

Workshop on Future Directions for the
NSF National Patterns R&D Resources Reports

September 6-7, 2012
Washington, DC

AGENDA

Thursday, September 6, 2012

8:45-9:00 am INTRODUCTIONS
Moderator: Karen Kafadar (*Workshop Chair*), Department of Statistics, Indiana University

9:00-9:45 WHAT IS *NATIONAL PATTERNS*?
Presenter: Mark Boroush, National Center for Science and Engineering Statistics, National Science Foundation

9:45-11:15 *NATIONAL PATTERNS* PURPOSES AND USES
Moderator: Chris Hill, George Mason University
Presenter 1: Kei Koizumi, White House Office of Science and Technology Policy
Presenter 2: David Mowery, University of California, Berkeley
Presenter 3: Martin Grueber, Battelle

	Presenter 4: Charles Larson, Innovation Research International Presenter 5: David Goldston, Natural Resources Defense Council
11:15 am- 12:15 pm	ADVANCES IN INTERNATIONAL COMPARABILITY OF *NATIONAL PATTERNS* DATA AND REPORTS Moderator: Fernando Galindo-Rueda, OECD Presenter 1: John Jankowski, National Center for Science and Engineering Statistics, National Science Foundation Presenter 2: Fernando Galindo-Rueda, OECD
12:15-1:15	LUNCH
1:15-2:30	R&D EXPENDITURE DATA FOR NONPROFIT ORGANIZATIONS The importance of R&D expenditure data for nonprofit organizations and the pros and cons of alternative ways of providing information on other nonprofits Moderator: Karen Kafadar, Indiana University Presenter 1: CNSTAT staff-methodological introduction Presenter 2: Jeff Alexander, Center for Science, Technology, and Economic Development, SRI International
2:30-3:30	REPORTING ON ADDITIONAL VARIABLES What variables not now collected on the four major NCSES surveys should be collected and tabulated in the future? Moderator: Stephanie Shipp, STPI Presenter: Kaye Husbands Fealing, CNSTAT, National Research Council
3:30-3:45	BREAK
3:45-5:15	IMPROVING COMMUNICATION What new tables or graphs should be included representing information currently collected on the four major NCSES surveys? Moderator: Karen Kafadar, Indiana University Presenter: Daniel Carr, Department of Statistics, George Mason University

Friday, September 7, 2012

9:00-10:00 am	POTENTIAL FUTURE METHODOLOGICAL USES OF ADMINISTRATIVE RECORDS Moderator: David Newman, University of California, Irvine Presentation: John King, Economic Research Service Presentation: CNSTAT staff-methodological issues
10:00-11:00	IDEAS FROM SMALL-AREA ESTIMATION Moderator: Eric Slud, U.S. Census Bureau Small-area estimation techniques useful for *National Patterns* tabulations Presenter: Julie Gershunskaya, Bureau of Labor Statistics
11:00-11:30	ADDITIONAL ISSUES FOR DISCUSSION Priorities for moving forward Moderator: Karen Kafadar, Indiana University

Appendix C

Biographical Sketches of Steering Committee Members and Workshop Presenters

STEERING COMMITTEE MEMBERS

Karen Kafadar is Rudy professor of statistics in the College of Arts and Sciences at Indiana University. Previously, she held positions at the National Institute of Standards and Technology, the RF/Microwave R&D Department at Hewlett-Packard, the Division of Cancer Prevention at the National Cancer Institute, and the University of Colorado, Denver. Her research focuses on robust methods, exploratory data analysis, and characterization of uncertainty in the physical, chemical, biological, and engineering sciences, and on methodology for the analysis of screening trials. She is a fellow of the American Statistical Association and is an elected member of the International Statistics Institute. She holds a B.S. in mathematics and an M.S. in statistics from Stanford University and a Ph.D. in statistics from Princeton University.

William B. Bonvillian is director of the Washington, DC, office of the Massachusetts Institute of Technology. Previously, he served as legislative director and chief counsel to U.S. Senator Joseph Lieberman. In these positions, his work has focused on national science policy, particularly in relation to research and development, technology, and innovation. Earlier in his career, he was a partner at a large national law firm and served as the deputy assistant secretary and director of congressional affairs at the U.S. Department of Transportation, where he worked on major transportation deregulation legislation.

Fernando Galindo-Rueda leads the science, technology, and innovation indicators unit in the Economic Analysis and Statistics Division of OECD's Directorate for Science, Technology, and Industry. He is responsible for supporting the work of the OECD Working Party of National Experts on Science and Technology Indicators where he coordinates the upkeep and further development of the Frascati family of internationally adopted statistical standards for the measurement of research and development, innovation, and technology and the publication of OECD publications in this area. Prior to joining the OECD, he was deputy director of business economics at the United Kingdom's Department of Economic Analysis. Previously, he also held positions in the UK Office for National Statistics and at the London School of Economics. He has a Ph.D. in economics from University College, London.

Christopher T. Hill is a professor in the School of Public Policy at George Mason University. His primary interests are in the history, design, evaluation, and politics of federal policies and programs intended to stimulate technological innovation in the commercial marketplace. He previously served as vice provost for research at George Mason University and held senior positions at the RAND Corporation, the National Research Council, the Congressional Research Service, the Massachusetts Institute of Technology, and the U.S. Office of Technology Assessment.

Joel L. Horowitz is the Charles E. and Emma H. Morrison professor of economics in the Department of Economics at Northwestern University. Prior to this position, he was on the faculty of the Department of Economics at the University of Iowa and a senior operations research analyst for the U.S. Environmental Protection Agency. He is a fellow of the Econometric Society and of the American Statistical Association and an elected member of the International Statistical Institute. His areas of interest are nonparametric and semiparametric methods. He has a B.S. in physics from Stanford University and a Ph.D. in physics from Cornell University.

David Newman is an associate research faculty member in the Department of Computer Science of the University of California, Irvine. His research interests are in machine learning, topic modeling, and text mining. He has received a Google Research Award for his work in topic mapping. He has a Ph.D. from Princeton University.

Stephanie S. Shipp is a research staff member at the Science and Technology Policy Institute at the Institute for Defense Analyses in Washington, DC. She specializes in the assessment of science and technology projects, programs, and portfolios. Her research involves innovation and competiveness with recent emphasis on advanced manufacturing, the role of federal laboratories, and funding of high risk/high reward research. Previously, she was director of the Economic Assessment Office in the Advanced Technology Program at the National Institute of Standards and Technology and held positions at the U.S. Census Bureau, the Bureau of Labor Statistics, and the Federal Reserve Board. She is a fellow of the American Statistical Association. She holds a B.A. from Trinity College, Washington, DC, and a Ph.D. in economics from George Washington University.

Eric V. Slud is a mathematical statistician at the Center for Statistical Research and Methodology at the U.S. Census Bureau. His previous position was as a professor in the statistics program at the University of Maryland. His areas of interest include stochastic processes, survival methods, and survey methodology. He is a fellow of the American Statistical Association.

Howard Wainer is distinguished research scientist for the National Board of Medical Examiners in Philadelphia, Pennsylvania. Previously, he served on the faculty of the University of Chicago, at the Bureau of Social Science Research, and as a principal research scientist in the Research Statistics Group at the Educational Testing Service. He has a long-standing interest in the use of graphical methods for data analysis and communication, robust statistical methodology, and the development and application of item response theory. He is a fellow of the American Statistical Association and of the American Educational Research Association. He holds a Ph.D. from Princeton University.

WORKSHOP PRESENTERS

Jeff Alexander is a senior science and technology policy analyst with SRI International. His research focuses on the areas of technology analysis, national and regional innovation policy, corporate and government research and development management, and collaborative innovation networks. Prior to joining SRI International, he was chief knowledge officer at New Economy Strategies, an economic development consulting firm, and vice president and director of research at Washington CORE, which provides technology market research and policy analysis to numerous international clients. He holds a B.A. in international relations from Stanford University and a Ph.D. in management and technology from the George Washington University School of Business.

Mark Boroush is project officer in the Research and Development Statistics Program for the National Center for Science and Engineering Statistics (NCSES) of the National Science Foundation. At NCSES, Boroush is responsible for national statistics and analysis on the status of the U.S. science and engineering enterprise, including the contributions to the nation's economy. Prior to his position at NCSES, Boroush was a senior policy analyst in the U.S. Department of Commerce's Technology Administration, where he was a member of the White House Office of Science and Technology Policy's Interagency Working Group on the Science of Science Policy. Before that, Boroush was the principal U.S. government delegate to the OECD's Working Party on Innovation and Technology Policy. He also worked at the National Institutes of Health and the Office of Technology Assessment. Boroush started out as a biochemist in basic life sciences research at Harvard University and the University of Michigan. His B.A. was from Case Western Reserve University. He also received a master's degree in economics and public policy from the University of Michigan.

Daniel Carr is a professor of statistics in the Volgenau School of Information Technology and Engineering at George Mason University. His principal research interests are in the fields of statistical graphics and visual analytics for use in communication, data exploration, hypothesis generation, and model criticism. He holds a B.A. from Whitman College, a master's degree in education from Idaho State University, and a Ph.D. in statistics from the University of Wisconsin.

Kaye Husbands Fealing is a study director with the Committee on National Statistics at the National Research Council and the William Brough professor of economics at Williams College. Previously, she was a visiting professor at the Hubert H. Humphrey School of Public Affairs at the University of Minnesota and served as a program director in the economics program at the U.S. National Science Foundation. She holds a B.A. in mathematics and economics from the University of Pennsylvania and a Ph.D. in economics from Harvard University.

Julie Gershunskaya is a mathematical statistician at the Bureau of Labor Statistics (BLS). Her areas of interest include survey sampling methodology, small-area estimation, robust estimation, and resampling methods. She has recently applied these methods to survey data on the Current Employment Statistics. She has a number of achievement awards from BLS and the U.S. Department of Labor. Dr. Gershunskaya received her B.S. and M.S. in mathematics from Moscow State University, and her Ph.D. in survey methodology from the University of Maryland, College Park.

David Goldston is director of government affairs for the Natural Resources Defense Council in Washington, DC. Previously, he held various positions on Capitol Hill, working primarily on science and environmental policy, and he served as chief of staff of the House Committee on Science. He has been a visiting lecturer at Princeton and Harvard Universities and a columnist for the journal *Nature*. He has a B.A. in history and has completed the course work for a Ph.D. in American history at the University of Pennsylvania.

Martin Grueber is a research leader for the technology partnership practice at Battelle. In this position, he coauthors the annual Battelle/*R&D Magazine* global research and development funding forecast. He previously worked as deputy director of the Rhode Island Economic Policy Council, manager of the Samuel Slater Technology Fund, and manager of the research staff for the Industrial Technology Institute. He has a B.S. in social science and an M.A. in geography from Michigan State University.

John Jankowski is director of the Research and Development (R&D) Statistics Program in the National Center for Science and Engineering Statistics at the U.S. National Science Foundation (NSF). His work has included the implementation of several major federal statistical R&D initiatives, including development of an R&D satellite account to the U.S. System of National Accounts, the collection of academic and biomedical cyberinfrastructure statistics, and conceptualization of the government's first data-linking project to track global R&D investments. Prior to joining NSF, he served as assistant director for strategic and policy analysis at the Distilled Spirits Council and as an economics researcher on energy and mineral issues at Resources for the Future. He holds degrees from Georgetown University and the Johns Hopkins School for Advanced International Studies.

John L. King is the acting director of the U.S. Department of Agriculture's (USDA) Office of the Chief Scientist and senior advisor for Agricultural Economics and Rural Communities, on detail from the Resource Environment and Science Policy Branch of the USDA Economic Research Service. His research has focused on innovation and science policy, including the influence of intellectual property, industry structure, and knowledge flows on public and private decision making in agricultural research and development. He has served on the National Science and Technology Council's interagency working group on Science of Science Policy and the Research in Engineering Education Science Performance Team since 2006, and more recently has been active in USDA implementation of the STAR METRICS initiative to develop new ways to examine the reach and impact of federal science. He codeveloped the Agricultural Biotechnology Intellectual Property database (http://www.ers.usda.gov/data/agbiotechip), a tool to examine industry structure and intellectual property ownership, and has collaborated with other science agencies on analyzing technology transfer policies and developing assessments of the economic impact of research. Prior to joining USDA in 1999, Dr. King received B.A. and Ph.D. degrees in economics from Vanderbilt University.

Kei Koizumi is assistant director for federal research and development (R&D) at the White House Office of Science and Technology Policy (OSTP). Before joining OSTP, he served as the director of the R&D Budget and Policy Program at the American Association for the Advancement of Science (AAAS) where he was the principal budget analyst, editor, and writer for the annual AAAS reports on federal R&D and for the continually updated analyses of federal R&D on the AAAS R&D website. He holds a B.A. in political science and economics from Boston University and an M.A. from the Center for International Science, Technology, and Public Policy at George Washington University.

Charles Larson is president of the Industrial Research Institute, Inc., a Washington, DC-based association of some 265 companies that perform research and development in the United States, Canada, Mexico, and abroad. He is a registered professional engineer and a fellow of the American Association for the Advancement of Science and of the American Society of Mechanical Engineers. He has a B.S. in mechanical engineering from Purdue University and an M.B.A. from Fairleigh Dickinson University.

David Mowery is William A. and Betty H. Hasler professor of new enterprise development at the Walter A. Haas School of Business at the University of California at Berkeley and a research associate of the National Bureau of Economic Research. Previously, he taught at Carnegie Mellon University. His research deals with the economics of technological innovation and the effects of public policies on innovation. His academic awards include the Raymond Vernon Prize from the Association for Public Policy Analysis and Management, the Economic History Association's Fritz Redlich Prize, the Business History Review's Newcomen Prize, and the Cheit Outstanding Teaching Award. He received undergraduate and Ph.D. degrees in economics from Stanford University.

COMMITTEE ON NATIONAL STATISTICS

The Committee on National Statistics (CNSTAT) was established in 1972 at the National Academies to improve the statistical methods and information on which public policy decisions are based. The committee carries out studies, workshops, and other activities to foster better measures and fuller understanding of the economy, the environment, public health, crime, education, immigration, poverty, welfare, and other public policy issues. It also evaluates ongoing statistical programs and tracks the statistical policy and coordinating activities of the federal government, serving a unique role at the intersection of statistics and public policy. The committee's work is supported by a consortium of federal agencies through a National Science Foundation grant.