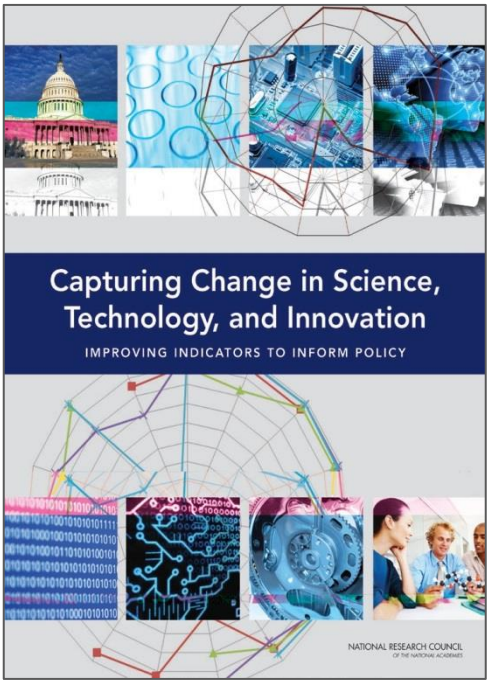
REPORT BRIEF

CAPTURING CHANGE IN SCIENCE, TECHNOLOGY, AND INNOVATION: IMPROVING INDICATORS TO INFORM POLICY

The availability of relevant, accurate, timely, and objective information on the health of the science, technology, and innovation (STI) enterprise is critical to addressing vital policy questions for the nations of the world, considered individually and collectively. For the United States, some of these questions are:



- How is STI'S contribution to productivity, employment, and growth in the broader U.S. economy changing in a world of economic globalization?
- What are the drivers of innovation that benefit the economy and society?
- Does the United States have the STI knowledge capital that it needs to move the nation forward and maintain competitiveness with other countries?
- What effect do federal expenditures on research and development (R&D) and on science and engineering education have on innovation, economic health, and social welfare, and over what time frame?
- What characteristics of industries and geographic areas facilitate productive innovation?

Since the 1950s, under congressional mandate, the U.S. National Science Foundation (NSF)—through its National Center for Science and Engineering Statistics (NCSES) and predecessor agencies—has produced regularly updated measures of research and development investment, employment and training in science and engineering, and other indicators of the state of

science and technology in the United States. Recently, NCSES has addressed the measurement of innovation in the corporate sector.

Changes in the structure of the U.S. and global economies and in sources of data pose not only significant challenges, but also opportunities for NCSES's efforts to monitor STI activities in the United States. One challenge is that what used to be the relatively simple task of tracking domestic R&D spending by a small number of U.S. manufacturers has evolved into the need to monitor STI activities across the globe and across a wide range of industrial and commercial sectors. Similarly challenging are the increasing velocity and changing character of the innovation system.

Affording both opportunity and challenge is the emergence of new types of information with which to track innovation, R&D, and the science and engineering workforce. Historically, statistical agencies such as NCSES have relied on sample surveys to collect consistent and unbiased information in these and other areas. In recent years, the amount of raw data readily available online has soared, creating possibilities for new STI indicators.

Microdata from administrative records and other sources have increasingly been used to produce measures of capacities and trends in the global STI system. Also, frontier methods are emerging for monitoring new product introductions through sophisticated web-scraping algorithms, tracking innovation activities through help-wanted ads, and tracing networks of scientists engaged in research through textual analysis of grant proposals, online working papers, and the published literature. Such data sources, although promising, are largely untested and therefore have uncertain biases.

These new challenges and opportunities led NCSES to ask the National Research Council's Committee on National Statistics (CNSTAT) and Board on Science, Technology, and Economic Policy (STEP) to convene an expert panel to consider whether NCSES's current STI statistical activities are properly focused to produce the information needed by policymakers, researchers, and businesses. The study, which was published in the report *Capturing Change in Science, Technology, and Innovation: Improving Indicators to Inform Policy* (2014), was particularly timely because of the America COMPETES Act of 2010, Section 505, which expanded and codified NCSES's role as a federal statistical agency charged to collect a broad expanse of STI-related information.

STI Indicator Topics Covered by the Panel

Actors	Activities	Linkages	Outcomes

• Individuals
• Collectives
  – Teams
  – Governments
  – Education and research institutions
  – Businesses
  – Private nonprofit organizations
	• Research
	• Invention
	• Development
	• Engineering/design
	• Innovation
	• Diffusion
	• Education
	• Training
	• Capital investment
	• Job mobility
	• Firm dynamics
	• Policy, regulation & governance
		• Grants
		• Contracts
		• Collaboration
		• Partnerships
		• Codevelopment
		• Copublication
		• Social networks
			• Knowledge stocks
			• Social capital
			• Intangibles
			• Products and services
			• Productivity
			• Product life cycles
			• Trade in S&T products
			• Trade in R&D services
			• Job mobility
			• Firm dynamics
			• Socioeconomic impacts/well-being

Key Indicators Suggested by Major Users of STI Indicators

Activities
- R&D
- Innovation
- Market capital investments

Outputs and Outcomes
- Commercial outputs and outcomes
- Knowledge outputs
- STEM education
- STEM workforce/talent
- Socioeconomic impacts/well-being

Linkages
- Organizations/Institutions (collaboratories, industry clusters, consortia, intellectual property rights and policies)
- Culture (public value of S&T, business climate, entrepreneurial activities, risk tolerance, social networks)

Subnational Indicators (state, county, and metropolitan tables; academic R&D expenditures; federal R&D expenditures; degrees granted in STEM; STEM graduate and workforce migration)

Key Data Needs and Questions about the Science and Engineering Enterprise

The CNSTAT and STEP expert panel consulted with a wide range of users of STI indicators through workshops and other outreach activities. The questions for which they sought answers included:

Growth, competitiveness, and jobs—What is the contribution of science, technology, and innovation (STI) activity to productivity, employment, and growth? What is the relative importance of technological innovation and non-technological innovation for economic growth?

STI activities—What are the drivers of innovation? How important are the following for advancing innovation: small businesses, large businesses, strategic alliances, technology transfer between universities and firms, academic researchers, government laboratories and procurement activities, and nonprofit organizations?

STI talent—What is the status of STEM education around the world? How much knowledge capital does the United States have?

Private investment, government investment and procurement—What impact does federal research spending have on innovation and economic health, and over what time frame? How large should the federal research budget be?

Institutions, networks, and regulations—What impacts are federal research programs (including federally funded research and development centers) having on entrepreneurial activities in S&E sectors? Where are the key gaps in the transfer of scientific and technological knowledge that undercut the performance of the STI system?

Global STI activities and outcomes—What can the United States learn from other countries, and what are other countries learning from the United States? In what technological areas are other countries accelerating?

Subnational STI activities and outcomes—How does innovation activity in a given firm in a given place contribute to that firm's productivity, employment, and growth, and perhaps also to these characteristics in the surrounding area? How are innovation supply chains working within a state?

Systemic changes on the horizon—How is the global STI ecosystem changing or evolving? What sectors, regions, and people will rise in prominence in the near future?

Key Findings

The panel identified a number of ways in which NCSES could improve its current STI indicators program with relatively little new investment in original data collection.

The panel also concluded that changes in the economy have made it necessary to develop new concepts and measures of STI and its economic and social impacts. NCSES may find it difficult to fund and supervise the development of new STI measures and methodologies, especially while continuing its current program of STI indicators. Nonetheless, continued production of only the traditional STI measures will provide an incomplete and possibly misleading indication of how well or poorly the economies of the United States and other countries are performing in generating the innovations in products, services, and production and delivery chains that lead to improved living standards.

Finally, in reviewing STI indicators around the globe, the panel found a depth and breadth of indicator programs that is truly remarkable. Nevertheless, after hearing presentations from different countries ranging across the African, Asian, and European continents, the panel was unable to identify any proven STI indicators or methodologies used by other countries that NCSES lacks and could easily and inexpensively adopt for its own program.

Key Recommendations for NCSES[†]

Measuring Innovation

The panel strongly believes that NCSES needs to improve its ability to measure and track innovation. Improved measures of innovation are necessary to assess the impact of federal, state, and local innovation policies, such as the amount and direction of federal R&D funding, support for STEM education at the graduate level, and regulation of new products and services.

In addition, having innovation output facilitates comparison of the United States with other countries in a key area that promotes economic growth. NCSES's mandate in the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (America COMPETES) Act (U.S. House of Representatives, 2010) includes the curation and dissemination of data on "United States competitiveness in science, engineering, technology, and research and development." Innovation is an important element for such comparisons. Without improved direct indicators of innovation outputs, policy analysis will continue to rely on imperfect indicators of innovation, such as number of patents granted; inputs to innovative activities, such as R&D spending and number of STEM workers; and broad performance measures for the economy, such as productivity.

RECOMMENDATION: The National Center for Science and Engineering Statistics should develop additional indicators for measuring innovation outcomes that would complement existing data on patents, inputs to innovation activities, and broader measures of economic performance.

RECOMMENDATION: The National Center for Science and Engineering Statistics should build on its Business Research and Development and Innovation Survey (BRDIS) to improve its suite of innovation indicators in the following ways:

- Tabulate the results from BRDIS using the same cutoffs for firm size (as well as comparable industry sectors) that are used by OECD countries in order to facilitate international comparisons;

- Fund research exploring precisely what companies mean when they report an innovation or report no innovation on BRDIS—such research would help inform current policy debates;

- Broaden the innovations tracked by BRDIS to encompass organizational and marketing innovations, as well as new data algorithms;

[†]**Note:** This is not a comprehensive list of all of the report's recommendations. A complete list can be found in the full report, *Capturing Change in Science, Technology, and Innovation: Improving Indicators to Inform Policy* (2014).

• Consider adding a section to BRDIS on unmarketed innovations, giving respondents the opportunity to cite the main reason these innovations have not yet been marketed or implemented;

• As funds permit, extend BRDIS to gather information on innovation-related expenditures in such areas as training and design; and

• Publish more results from BRDIS that link innovation to business characteristics, including the amount of research and development spending by U.S.-based companies outside of the United States. Production and distribution of such cross-tabulations should be timely, and they should address contemporary policy questions.

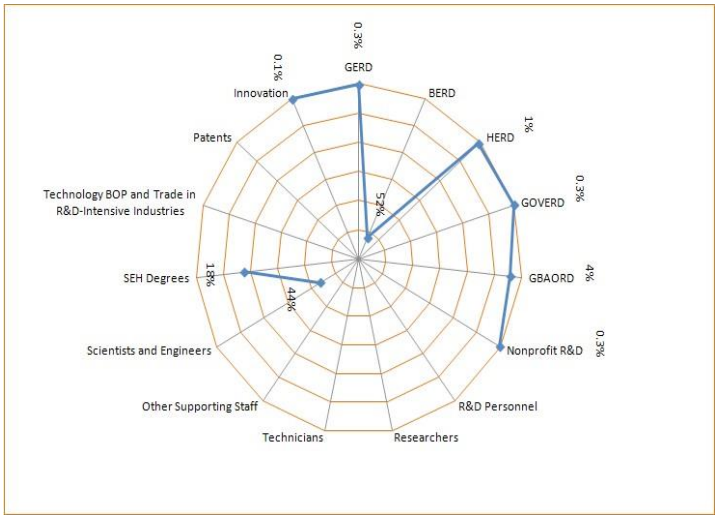
RECOMMENDATION: The National Center for Science and Engineering Statistics should begin a project to match its Business Research and Development and Innovation Survey data to data from ongoing surveys at the U.S. Census Bureau and the Bureau of Labor Statistics. It should use the resulting data linkages to develop measures of activities by high-growth firms, births and deaths of businesses linked to innovation outputs, and other indicators of firm dynamics, all of which should be tabulated by geographic and industry sector and by business size and business age to facilitate comparative analyses. NCSES should conduct a sensitivity analysis to fine-tune meaningful age categories for high-growth firms.

RECOMMENDATION: The National Center for Science and Engineering Statistics should make greater use of business practice data to track research and development spending and innovation-related jobs at a more detailed geographic and occupational level than is possible with government survey data.

Measuring Knowledge

Knowledge generation, diffusion, and use, as well as conduits for knowledge flows, are all key elements for economic growth. Therefore, it is critically important for NCSES to produce indicators of these varied dimensions of knowledge at the national, international, and subnational levels.

Quite a few data elements, such as research and development (R&D), patents, bibliometrics, and trade in technology, capture knowledge generation, networks, and flows (referred to as "the three K's").



NCSES's Concentration in STI Subtopics

NCSES has been collecting these data for several decades in order to publish indicators on these topics, drawing on both its own and other data sources, such as the Bureau of Economic Analysis for data on global multinational R&D activities. International R&D is well covered by BRDIS. While NCSES has good measures of knowledge creation, however, a number of complex issues remain unaddressed, and challenges for measurement remain in the area of knowledge flows.

RECOMMENDATION: The National Center for Science and Engineering Statistics should make greater use of data from its Business Research and Development and Innovation Survey to provide indicators of payments and receipts for research and development services purchased from and sold to other countries. For this purpose, NCSES should continue collaboration with the U.S. Bureau of Economic Analysis on the linked dataset.

RECOMMENDATION: The National Center for Science and Engineering Statistics should continue to report statistics on knowledge-based capital and intangible assets obtained from other agencies as part of its data repository function. In addition, NCSES should seek to use data from the Business Research and Development and Innovation Survey on research and development and potentially also on innovation-related expenditures as valuable inputs to ongoing work in this area.

RECOMMENDATION: The National Center for Science and Engineering Statistics should develop a suite of indicators that can be used to track the development and diffusion of general-purpose technologies, including information and communication technologies, biotechnology, nanotechnology, and green technologies. NCSES should attempt to make greater use of data from the Business Research and Development and Innovation Survey for this purpose while also exploring the use of other sources, such as patent and bibliometric data.

Measuring Human Capital

NCSES produces a rich set of human capital indicators, ranging from elementary school education to postdoctoral training to employment in science, technology, engineering and mathematics (STEM) occupations. These measures convey the magnitude, composition, and quality of human capital; funding of education; deployment of human capital in industry, government, and academe; and human capital creation within industry. NCSES's academic surveys provide information on academic funding for science and engineering (S&E) research, federal spending among fields of study, and spending on academic infrastructure. The education surveys provide the data needed to measure the pipeline and pathways into higher education in STEM fields. Measured by online downloads (unadjusted for length of views), the most widely viewed statistics in the National Science Board's *Science and Engineering Indicators* (SEI) relate to education and the workforce, making these statistics one of NCSES's most important products and making NCSES an international leader in S&E education statistics.

RECOMMENDATION: The National Center for Science and Engineering Statistics should do more to exploit existing longitudinal data. Specifically, NCSES should exploit the longitudinal panel structure of the Survey of Doctorate Recipients (SDR) in the following ways:

- Create indicators of researcher mobility over time, by constructing longitudinal weights for the SDR that take account of changes in the sample and target population over time—these weights should be constructed both for subsequent survey cycles and for existing data;

- Create a dynamic database for researcher use in which data from the SDR over time would be linked at the level of the individual; and

- Enhance coverage of recent doctorate recipients to better track their initial employment and career path in the first years after they receive their Ph.D., which could potentially be accomplished by including an additional module in the SDR or by exploiting that survey's longitudinal capacities, or both.

RECOMMENDATION: The National Center for Science and Engineering Statistics should draw on the Longitudinal Employer-Household Dynamics Program (occupations) and the Baccalaureate and Beyond Longitudinal Study (education levels) to create indicators of labor mobility. NCSES should focus in particular on industries that have been

experiencing high growth and/or those in which the United States has a strong competitive advantage. Also relevant would be examining skill sets of firms with high growth.

RECOMMENDATION: The National Center for Science and Engineering Statistics should enhance indicator coverage of individual science, technology, engineering, and mathematics groups such as early-career doctorate recipients, master's degree holders, and community college graduates. NCSES already distinguishes between bachelor's and master's degree holders in many of its statistics. Stay rates at different education levels by demographic characteristics such as gender, race/ethnicity, disability, and country of origin should be included.

RECOMMENDATION: The National Center for Science and Engineering Statistics should explore methods for exploiting the full-text resources of dissertation databases to create indicators on selected topics both within and across scientific fields and on the relatedness of different fields.

RECOMMENDATION: The National Center for Science and Engineering Statistics should consider using American Community Survey data to produce indicators that can be used to track the salaries of science, technology, engineering, and mathematics occupations and/or college graduates receiving degrees in different fields and at different degree levels.

RECOMMENDATION: The National Center for Science and Engineering Statistics should consider adding questions to the Business Research and Development and Innovation Survey on the types of skill sets used by businesses to develop and implement innovations. The results would provide data on and indicators of innovative firms' demand for skills.

Paradigm Shift in Data Collection & Analysis

Traditional surveys face increasing expense, declining response rates and lengthy time lags before data can be delivered to users. At the same time, alternative data sources and tools for data extraction, manipulation, and analysis are evolving rapidly. NCSES will need to experiment with nontraditional data sources for indicator development, used alone and in combination with surveys. A key consideration is how to measure the quality of the resulting estimates.

RECOMMENDATION: The National Center for Science and Engineering Statistics should use research awards to support the development and experimental use of new sources of data to understand the broad spectrum of innovation activities and to develop new measures of science, technology, and innovation. NCSES should also support the development of new datasets to measure changing public perceptions of science, international trade in technological goods and services, new regions for entrepreneurial activity in science and technology, and pre-commercialized inventions.

An Example of Using Non-Traditional Data Sources: Estimating Employment Shifts from LinkedIn Data

LinkedIn's data science team (The Noisy Channel, 2012) recently collaborated with the White House Council of Economic Advisors to identify the industries that grew and shrank the most during the 2008-2009 recession and the subsequent recovery. By following people who were site members in 2007 longitudinally through 2011, they were able to see the rapid growth in renewable energy and Internet companies, as well as sharp declines in newspapers, restaurants, and the retail sector. The cohort they followed numbered in the tens of millions, and LinkedIn contains detailed data on its members' educational backgrounds, so one can readily imagine conducting similar analyses restricted to workers with science, technology, engineering, and mathematics (STEM) degrees. Moreover, one of the study's authors says that, in principle, LinkedIn could track such changes in real time.

The Noisy Channel. (2012). *Data Science at LinkedIn: My Team*. Available at http://thenoisychannel.com/2012/05/17/data-science-at-linkedin-myteam/ [December 2012].

PANEL ON DEVELOPING SCIENCE, TECHNOLOGY, AND INNOVATION INDICATORS FOR THE FUTURE

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