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Innovation in the US Government

Joshua R. Bruce and John M. de Figueiredo

9.1 Introduction

In recent years, the US government has spent over $120 billion annually on research and development (R&D).[1] In addition, each OECD country spends the equivalent of billions of dollars every year to support technological infrastructure and advancement to further science and research. The literature on governments' contributions to the worldwide innovation ecosystem has focused on two areas: first, the role of government policy, such as intellectual property rules, tax credits, and infrastructure investments, to support private-sector innovation (e.g., Bloom, Van Reenen, and Williams 2019); and second, the role of government funds targeted to the private and nonprofit sectors to enhance the direction, productivity, and efficiency of R&D (e.g., Azoulay et al. 2019).

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1. For a historical overview of federal R&D spending levels, see the Congressional Research Service's "U.S. Research and Development Funding and Performance: Fact Sheet (Updated January 24, 2020)," available at: https://crsreports.congress.gov/product/pdf/R/R44307 (last accessed March 13, 2020).

While both of these literatures are important for understanding the government's role in innovation, comparatively little academic work has been done examining the direction and effectiveness of government research itself. In fiscal year (FY) 2018, the US government spent over $36 billion on "intramural" R&D—that is, the innovation that the government funds and conducts itself—more than any individual company in the US.[2] In recent years, the federal government has employed approximately 200,000 scientists, just under half of whom engage in R&D. Federal civil service scientists prolifically invent, innovate, patent, and publish. Yet despite the number of personnel and the size of their research budgets, there is almost no systematic or comprehensive scholarship on the US governments' intramural R&D efforts.

Our chapter begins addressing this issue with a look into government innovation. We bring together a variety of data sets to provide an initial comprehensive picture of innovation in government. Some of these data sets, such as those on funding from the National Science Foundation (NSF), are widely available. Others, such as a data set on US government scientists and R&D effort, have rarely been employed and never used in this capacity. Additional data sets, such as those linking US government scientists to patents, have been available but have not been mapped comprehensively in the innovation literature. In this chapter, we bring these and other data together at an aggregate level to understand the inputs and outputs to government intramural innovation (see appendix table 9.A.1 for a complete list). The focus in this chapter is on the US government, but the approaches here are translatable to any government entity for which data are available.

Nearly half of all US government R&D expenditures over the past 50 years went to the Department of Defense (DOD). The Department of Health and Human Services, which contains the National Institutes of Health and Centers for Disease Control and Prevention, was the second largest recipient of federal R&D allocations. The Department of Energy, the National Aeronautics and Space Administration, and the NSF round out the top five R&D-funding agencies, responsible for 90 percent of all federal R&D spending. The concentration of spending on national defense, biomedical science, and physical sciences/engineering is reflected in both the federal scientific workforce, which is predominantly employed in these agencies, and the types of innovations generated with federal dollars, which hew toward these agencies' missions. This leaves comparatively far fewer resources and personnel focused on education, housing, and social science

2. As a point of comparison, Amazon, the top R&D spending company in the US, spent $22.6 billion on R&D in 2017; Alphabet/Google, the next-largest spender, allocated $16.6 billion. See https://www.vox.com/2018/4/9/17204004/amazon-research-development-rd (last accessed March 13, 2020).

research, though innovations in these areas are more difficult to measure, as we discuss below.

This chapter seeks to make four contributions. First, we provide a broad analysis of government intramural innovative inputs and outputs and, we believe, the first comparative analysis of intramural and extramural research efforts. In this capacity, we intend to provide a set of facts and regularities about government innovation. Second, we argue that much of government innovation, broadly defined, is difficult to measure. Innovation has many dimensions, and much of the economics literature is focused on technological innovation. By constraining analyses to government technological innovation, researchers will miss much of the innovation that occurs in government. Third, even if we limit our analysis to technological innovation, traditional output measures of technological innovation will be heavily weighted toward such agencies as the DOD, the National Aeronautics and Space Administration, and the Department of Energy. This is because the nature of innovation in these agencies will be oriented toward engineering and physical science, where innovative outputs are somewhat easier to catalog with patents. However, innovations in agencies that rely on mathematics, social science, and data analytics, for example, will often be missed by this measure. Overall, using traditional measures of patents as a measure of innovative output, while informative, will be biased by the nature and variety of innovations that occur in government. Finally, the data show that while the amount of government funding for R&D has increased substantially over the past few decades, the number of government scientists has not. The government has shifted away from intramural research and toward a more extramural science orientation. In making this shift, the government may increase the diversity and efficiency of innovation, but it risks not developing sufficient internal innovative capability to manage, direct, and develop science and research. We further discuss potential implications of this trend in the conclusion.

The chapter proceeds as follows. In the next section, we provide a brief overview of the US government. In section 9.3, we develop a classification system for different types of government innovation. Section 9.4 discusses inputs into government intramural innovation, with a focus on funding and manpower. Section 9.5 analyzes the outputs from intramural innovation, with a discussion of patents and other measures. In section 9.6, we briefly outline state government contributions to intramural R&D. We conclude in section 9.7 with a brief discussion of implications and future research.

9.2 Overview of the US Government

We begin with an overview of the US government, focusing on money (budget/appropriations) and manpower (human capital) as underlying indicators of government innovative input and capabilities. In fiscal year 2020, US government budgeted expenditures are estimated to total $4.6 trillion.[3] Approximately $2.1 trillion of the budget is allocated to Social Security, Medicare, and interest on the debt. Approximately $1.5 trillion is spent on Medicaid, national defense, and other mandatory programs. Approximately $1 trillion remains for every other function of the government, from land management to foreign relations to agricultural research.

The US government employs approximately 4.3 million full-time equivalent (FTE) workers in 2020. During 1998–2018, US federal employees represented an average of 3.7 percent of the US FTE workforce.[4] As of 2020, about half of these employees are in the uniformed military (1.4 million) and the Post Office (585,000), while the other half are civilians employed in executive branch agencies.[5] In the rest of this chapter, when referring to government personnel, we focus on full-time, nonseasonal executive branch civil servants.

Approximately 70 percent of these federal employees are on the General Schedule (GS) pay plan. This plan has 15 major levels, called "grades," with each movement upward in grade being a promotion in the government.[6] Grade level is a convenient summary statistic for the skill level, education, and expertise of civil servants.[7] Figure 9.1 shows the distribution of federal employees by grade in 1988 and in 2011 along with the median grade in these two fiscal years (Bolton and de Figueiredo 2016). The figure shows a shift from a bimodal distribution of grades of federal workers in 1988 to a more unimodal distribution of workers by 2011. More importantly, the average and median grade increased markedly over that 24-year period, following a substantial upskilling in the federal workforce. Figure 9.2 shows where this upskilling has taken place in the federal workforce by looking at the number of civil servants employed in five occupational categories over time (Bolton and de Figueiredo 2016). Figure 9.2 illustrates the drastic decline in the share of clerical workers in the government (from 24 percent to 7 percent),

3. Congressional Budget Office (CBO) projection for FY2020, as of January 28, 2020. See: https://www.cbo.gov/topics/budget. If this spending were entirely production, it would represent around a fifth of the US economy. However, the budget includes substantial transfers. This estimate was created before the COVID-19 pandemic was recognized as a major health threat in the US, which added roughly $1.9 trillion to FY2020 federal spending as of November 30, 2020; for more, see: https://www.usaspending.gov/disaster/covid-19 (last accessed January 25, 2021).

4. See the Bureau of Economic Analysis (BEA) National Accounts (NIPA), "Table 6.4B. Full-Time and Part-Time Employees by Industry" (last accessed February 28, 2020).

5. There are roughly 75,000 FTE individuals employed in the legislative and judicial branches. For more, see the Congressional Research Service's "Federal Workforce Statistics Sources," updated Oct. 24, 2019: https://fas.org/sgp/crs/misc/R43590.pdf.

6. Each grade also has 10 steps. One convenient way to think about grades is as promotions; steps are pay increases for tenure and experience with a job.

7. The starting grade for someone with 4-year college degree, for example, is grade 5; a master's degree is about grade 9; a PhD is grade 12. For more on the GS system, see the Office of Personnel Management's overview at https://www.opm.gov/policy-data-oversight/pay-leave/pay-systems/general-schedule/.

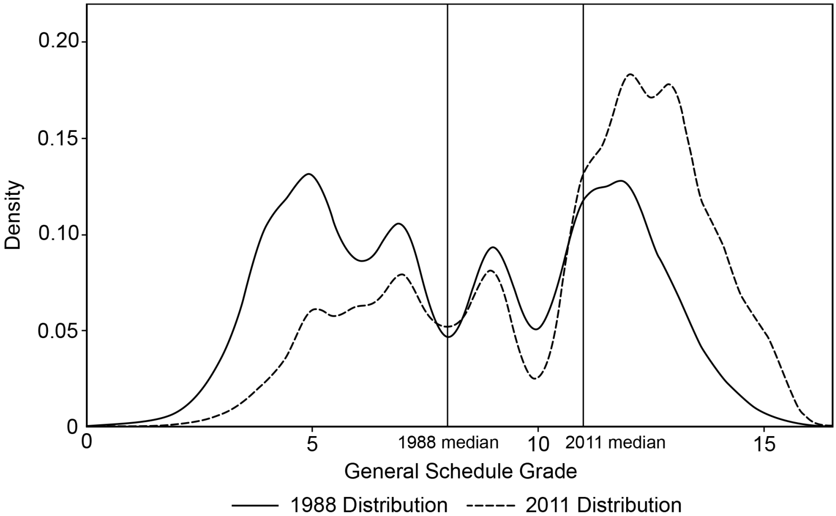

Fig. 9.1 The GS grade distribution, FY1988 vs. FY2011
Source: Bolton and de Figueiredo (2016).

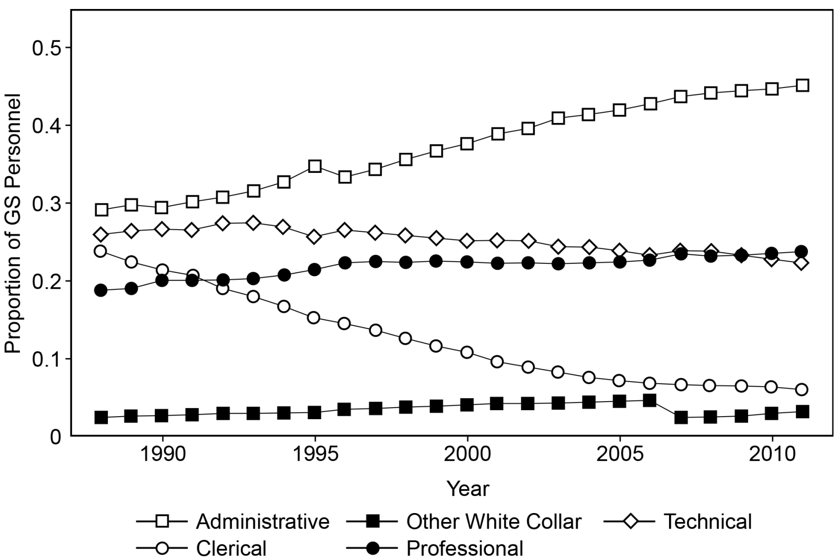

Fig. 9.2 Federal personnel occupation categories, FY1988–2011
Source: Bolton and de Figueiredo (2016).

commensurate with a significant increase in the proportion of more highly skilled "administrators" (from 29 percent to 48 percent).

The literature on public administration has identified (at least) two causes of this upskilling in the workforce. The first is the rise of computers and automation, which has allowed the federal government to remove the large clerical and typing pools that were essential to the operation of the government in the 1960s and 1970s (Rein 2014). Second, there has been a substantial increase in the amount of outsourcing by the government, which has increased the need for more highly skilled procurement specialists, contract managers, accountants, and auditors (Light 2017). This upskilling and outsourcing of the federal workforce has translated into a fourfold increase in the number of budget dollars per employee over this 24-year period (Bolton and de Figueiredo 2016).[8]

9.3 Classification of Government Innovations

The public administration literature has considered a variety of approaches to classifying innovation (e.g., Arundel, Bloch, and Ferguson 2019; Chen, Walker, and Sawhney 2019; Hartley 2005; Vries, Bekkers, and Tummers 2016). Based on these approaches, we developed a four-category classification system that we believe describes most innovation carried out by federal employees and the federal infrastructure. While there is some overlap among these categories, together they describe much of the innovation carried out by the federal government.

The first category of government innovation is technological innovation. These innovations involve technically new and novel inventions and improvements that are consistent with the broader economics literature on technical change. Examples of government innovations in this category include diverse innovations, such as hybrid vehicle control methods, inhibitors of integrase production to combat HIV, and snake repellant identification methods.

A second type of government innovation is organizational innovation. These are innovations that advance the way the government operates and is "organized," often resulting in greater administrative efficiency. Examples of organizational government innovations include the elimination of typing pools and introduction of computers, the implementation of oral proposals for some types of government procurement, novel approaches to managing civil service employees, and the crowdsourcing of citizen science.

A third type of government innovation is regulatory innovation. Unlike the private sector, the federal government's responsibilities include defining and administering the laws of the country through a regulatory apparatus.

8. Baumol (1967) theorized that some sectors of the economy, such as governmental services, would see only limited success in innovating because of limitations to labor productivity.

Regulatory innovations include the process of making rules and regulations, enforcing those regulations, and adjudicating them. The government is continually evolving the rule-making process within the rubric of the Administrative Procedures Act of 1946, through such recent innovations as negotiated rulemaking, electronic rulemaking (e-rulemaking), reformation of the drug approval process, and fast-track product recalls.

The fourth type of government innovation is also not found in the private sector: policy innovations. These innovations encompass the new types of regulatory policies and frameworks implemented by the administrative state to achieve desired social welfare and policy objectives. These are the actual policies and regulations themselves that the government has never implemented before, rather than mechanisms of regulatory process. Examples of policy innovations include the cap and trade program to combat air pollution and spectrum auctions to allocate broadcast rights over electromagnetic wave ranges. These policy innovations are not policies implemented by the government to encourage innovation per se, but they may lead to technological innovation in the economy (as a second-order effect, in most cases).

Although the focus of the literature (and the remainder of this chapter) is on technological innovation, such innovations represent only a fraction of all innovation that is conducted by the US government. The Ash Center at the Harvard University Kennedy School of Government has been accepting nominations for its Innovation in American Government Awards since 1985.[9] Over the past 35 years, they have received thousands of nominations for the awards, with nearly all nominations being in the organizational, regulatory, and policy innovation areas. Table 9.1 provides a list of the US agencies and their programs that won this award from 1995 to 1999, illustrating the breadth of programs and government entities engaged in innovation, much of which would not be captured by traditional innovation measures.

One challenge in the statistical literature on government innovation is that no standardized or readily available measure of government innovation applies across all areas of government or all types of innovation. Even in specific agencies, these types of innovations are hard to consistently measure across time. If we are to understand the full scope of innovation in the government, future research should aspire to develop measures that are consistent across agencies and across time, and available in statistically useful ways, to capture the government's true innovative power. Technological innovation is only the tip of the iceberg. Unfortunately, we do not solve this problem in this chapter. Instead, we examine the most readily measurable area of government innovation—technological innovation—about which relatively little is currently known outside the National Institutes of Health (e.g., Li, Azoulay, and Sampat 2017).

9. Federal agencies have been able to apply for the awards since 1995. See: https://ash.harvard.edu/iag-history.

Table 9.1 Innovation in American government award examples, 1995–1999

Agency	Program title	Year
Department of Defense	National Defense on the Offense	1995
US Air Force	Ozone Depleting Chemical Elimination	1995
Bureau of Reclamation	Reinvention of the Bureau of Reclamation	1995
Pension Benefit Guaranty Corporation	Early Warning Program	1995
Immigration and Naturalization Service	Operation Jobs	1995
Federal Emergency Management Agency	Consequence Assessment Tool Set and Operations Concept	1996
Housing and Urban Development	Consolidated Planning/Community Connections	1996
Department of Labor	No Sweat: Eradicating Sweatshops	1996
Food and Drug Administration	Reform of the US Drug Approval Process	1997
Internal Revenue Service	TeleFile	1997
Department of Defense	Best Manufacturing Practices Program	1998
Consumer Product Safety Commission	Fast-Track Product Recall Program	1998
US Forest Service	Northern New Mexico Collaborative Stewardship	1998
Centers for Disease Control	PulseNet	1999
Housing and Urban Development	Continuum of Care	1999

9.4 Inputs to Government Technological Innovation

In this section, we focus on the two main inputs to technological innovation by the government: funding and human capital.

9.4.1 Funding by the Government

The US government spent over $120 billion on R&D in FY2018.[10] Figure 9.3a shows federal spending on R&D for 51 years by major government agencies and demonstrates that the DOD has consumed roughly 50 percent of the R&D spending for most of the past half-century. After the DOD, the Department of Health and Human Services (HHS), which houses the National Institutes of Health (NIH) and the Centers for Disease Control and Prevention (CDC), the Department of Energy (DOE), which conducts a substantial amount of nuclear weapons and energy generation research, the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF), in order, possess the next largest government R&D budgets. Together, these agencies comprise over 90 percent of federal R&D dollars appropriated.

Agencies allocate these appropriated funds to researchers, who then perform R&D. Figure 9.3b shows how the money was allocated by the type of entity performing the actual R&D effort. In FY2018, 31 percent ($39.8 billion) was directed to private sector companies; 24 percent ($31.5 billion)

10. A note on federal spending nomenclature: "outlays" represent actual money spent in fulfillment of R&D, whereas "obligations" represent contracted R&D effort backed by Congressional appropriations, which often includes money to be spent in future fiscal years, leading to different amounts, depending on which term is being used.

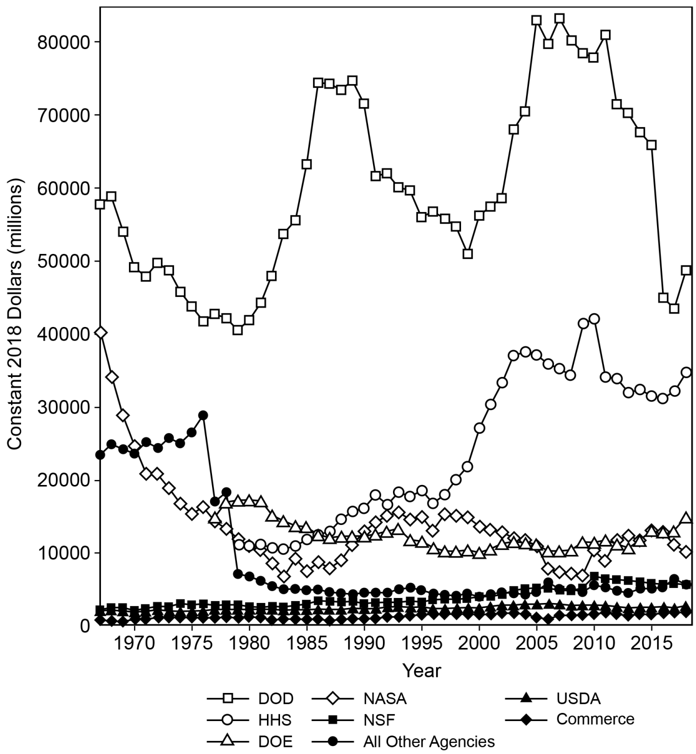

Fig. 9.3a Distribution of federal spending across agencies, 1967–2018
Source: NSF. Includes research, development, and plant expenditures, in 2018 dollars.

went to higher education and universities; 10 percent ($12.5 billion) went to the operation of federally funded R&D centers (FFRDCs),[11] such as the Jet Propulsion Lab (managed by the California Institute of Technology) or Los Alamos National Lab (managed by the nonprofit and university consortium Triad National Security, LLC); and 28 percent ($36 billion) of federal R&D obligations were allocated to "intramural" research—that is, R&D conducted by federal government civil servant scientists and researchers. The remaining 7 percent of R&D obligations ($9.7 billion) were directed to other nonprofit organizations, state and local governments, and international R&D.

Academic research has spent a substantial amount of energy examin-

11. FFRDCs may be managed by the federal government, universities, private-sector businesses, or other nonprofit organizations. For the purposes of this chapter, all funding directed to the operation of FFRDCs by nongovernmental organizations (also known as GOCOs) has been combined into a single category; government-run FFRDC (also known as GOGOs) obligations are included in the "intramural" category by the NSF.

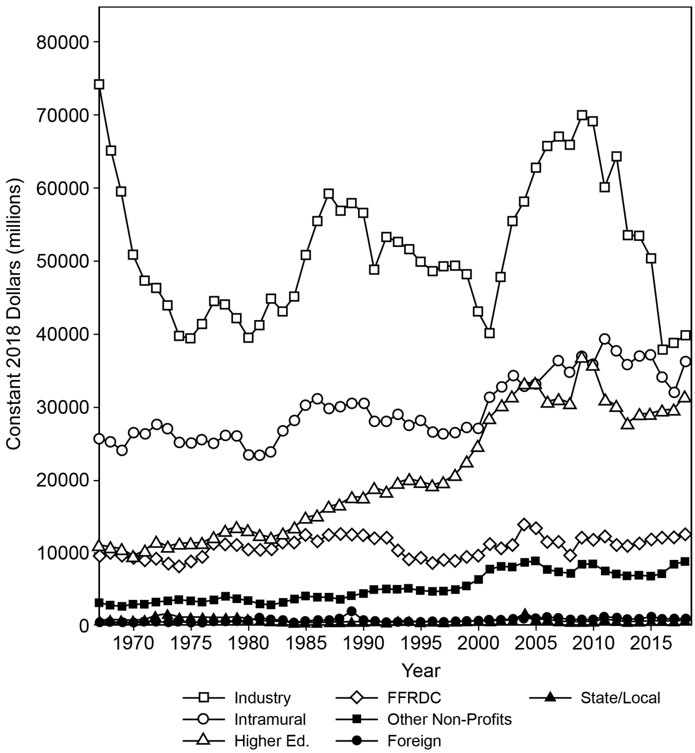

Fig. 9.3b Performers of Federally Funded R&D, 1967–2018
Source: NSF.
Note: Includes research, development, and plant obligations, in 2018 dollars.

ing the allocation of government money to universities (Lanahan, Graddy-Reed, and Feldman 2016; Mansfield 1995), the private sector (Azoulay et al. 2019; Bruce, de Figueiredo, and Silverman 2019; Howell 2017), and the FFRDCs (Jaffe, Fogarty, and Banks 1998; Jaffe and Lerner 2001; Jaffe and Trajtenberg 1996). These papers have examined both the direct effects of federal funds on scientific effort, as well as the interconnections between federally supported R&D and other sectors' outcomes. However, there have been comparatively few studies of intramural research focused on understanding the work and productivity of government scientists. Therefore, in the remainder of the chapter, unless specifically noted, we examine only intramural science.

9.4.2 Human Capital of the Government

A second key input into government innovation is the manpower that the government dedicates to the task. We have obtained from the Office of Personnel Management (OPM) elements of the Central Personnel Data File, which contains information on every federal government civilian employee

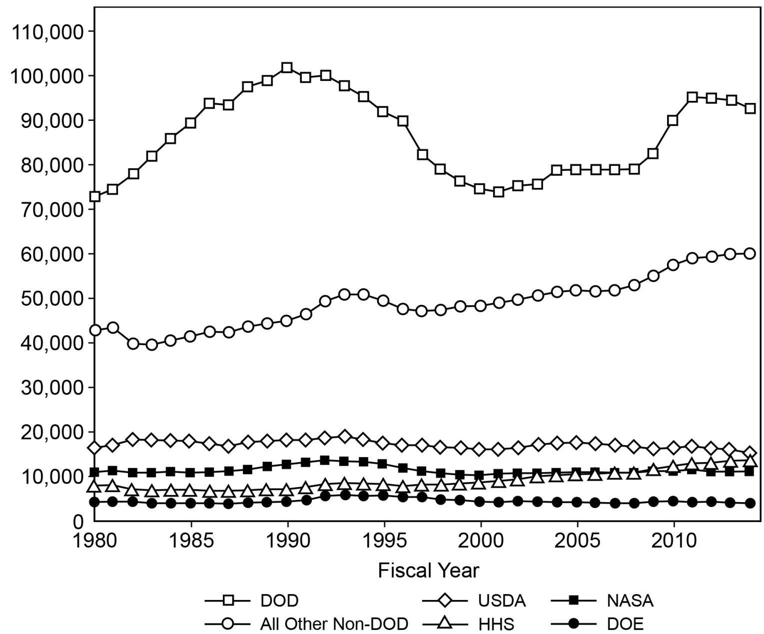

Fig. 9.4a Total federal scientific employment, 1980–2014

who does not work in a sensitive position or sensitive agency. A detailed personnel data set spans 1988 to 2011; a less detailed data set spans 1980 to 2014. All personnel data presented herein are drawn from one of these two data sets unless otherwise noted.

We begin by examining the number of individuals in 68 distinct scientific occupations, whom we call "scientists."[12] The number of scientists in the government rose from 155,000 in 1980 to just under 200,000 by 2014. These scientists, as illustrated in figure 9.4a, are distributed across agencies, with approximately half of the scientists in the DOD and the remaining gov-

12. The 68 scientific occupations and their categorization in the federal government broadly represent academic scientific disciplines. The occupations included are: (life sciences) microbiology, pharmacology, ecology, zoology, physiology, entomology, toxicology, botany, plant pathology, plant physiology, horticulture, genetics, soil conservation, soil science, agronomy, fish biology, wildlife biology, animal science, general health science, veterinary medical science; (math and statistics) general math and statistics, actuarial science, operations research, mathematics, mathematical statistics, statistics; (engineering and computer science) computer science, general engineering, safety engineering, fire protection engineering, material engineering, architecture, civil engineering, environmental engineering, mechanical engineering, nuclear engineering, electrical engineering, computer engineering, electronics engineering, bioengineering and biomedical engineering, aerospace engineering, mining engineering, petroleum engineering, agricultural engineering, chemical engineering, industrial engineering; (physical sciences) general physical sciences, health physics, physics, geophysics, hydrology, chemistry, metallurgy, astronomy and space science, meteorology, geology, oceanography, cartography, geodesy; (social sciences) social science, economics, workforce research and analysis, geography, history, psychology, sociology, general anthropology, archeology.

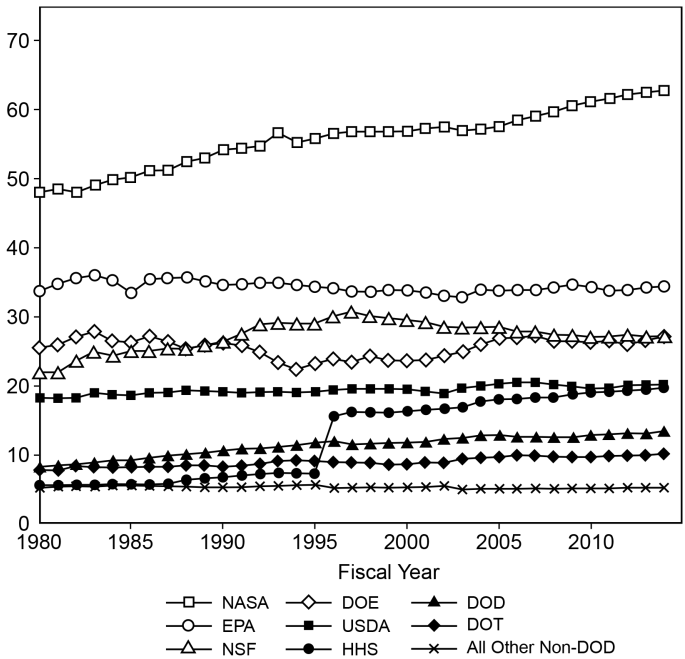

Fig. 9.4b Percentage of employees in scientific occupations, 1980–2014
Note: Discontinuity in HHS line due to Social Security Administration being re-organized outside HHS in 1995.

ernment scientists being found, in order of prevalence, in the Department of Agriculture (USDA), HHS, NASA, and DOE. Other agencies, such as the Department of Commerce (Commerce), the Department of Veterans Affairs (VA), the Environmental Protection Agency (EPA), the Department of Interior (DOI), and the Department of Transportation (DOT) also possess a notable number of scientists.

Figure 9.4b shows the concentration and intensity of scientific effort in these government agencies by examining the percentage of all agency employees in scientific occupations. Perhaps not surprisingly, NASA has consistently had the highest concentration of scientific personnel, followed by the EPA, NSF, DOE, USDA, and HHS. Many of these agencies' smaller total workforces belie the science intensity in the agencies.

Despite being employed in scientific occupations, not all scientists in the government are primarily engaged in research. OPM classifies each federal scientist in one of 19 different primary activity categories, known as a "functional classification."[13] We focus on a subset of the functional classifications

13. For more, see "Appendix 2: Functional Classification for Scientists and Engineers" in OPM's *Introduction to the Position Classification System*, available at: https://www.opm.gov

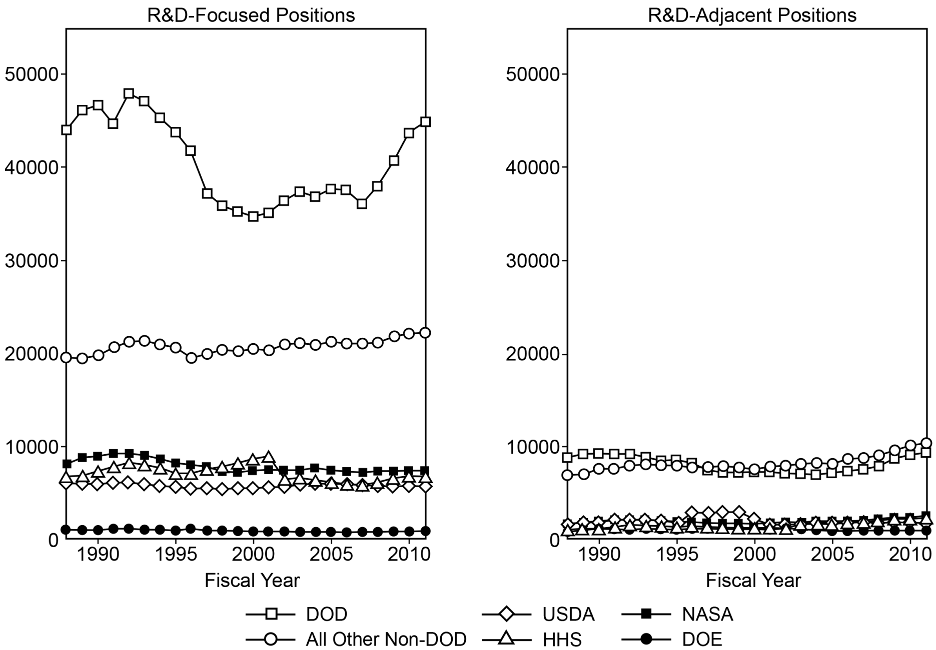

Fig. 9.5a Scientists by R&D functional classification, 1988–2011

Note: R&D-focused positions are those classified as Research, Development, Data Analysis, or Testing & Evaluation. R&D-adjacent positions are those classified as R&D Grant Administration, Scientific and Technical Information, or Management (of Science).

to identify two groups of scientists: R&D-focused and R&D-adjacent.[14] We classify scientists as being in an R&D-focused position if their primary job is to do research, development, testing and evaluation, or data analysis. We classify scientists as being in an R&D-adjacent position if they are engaged primarily in R&D grant administration, scientific and technical information processing/dissemination, or the management of science.

Figure 9.5a illustrates the distribution of scientists in R&D-focused and R&D-adjacent positions over a 24-year period in major scientific agencies, from which several important patterns emerge. First, about 87,000 government scientists engage in R&D-focused work in the latest years where data are available, while about 26,000 government scientists are engaged

/policy-data-oversight/classification-qualifications/classifying-general-schedule-positions/positionclassificationintro.pdf (last accessed February 15, 2020).

14. There is a third group of scientific personnel whose work is not clearly R&D related, though they are employed in scientific occupations (e.g., a civil engineer with a functional classification of "production," which is focused on building construction). These scientific personnel in non-R&D positions are included in the total scientists employed by the federal government discussed earlier but are not included in this R&D-specific discussion.

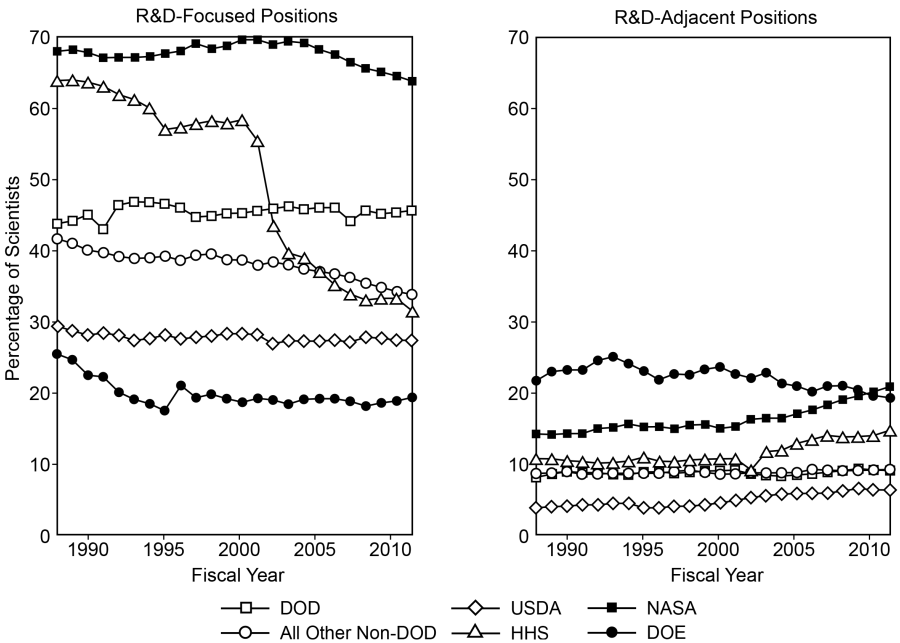

Fig. 9.5b Percentage of scientists by R&D functional classification, 1988–2011

Note: R&D-focused positions are those classified as Research, Development, Data Analysis, or Testing & Evaluation. R&D-adjacent positions are those classified as R&D Grant Administration, Scientific and Technical Information, or Management (of Science).

in R&D-adjacent activities. The DOD again has the largest share of federal R&D scientists; NASA, HHS, USDA, and DOE have substantial numbers of R&D-focused scientists as well. Figure 9.5b examines the percentage of scientists by R&D area.[15] While the DOD again features prominently, NASA and HHS have comparatively high levels of R&D-focused scientists as well. Figure 9.4b and 9.5b together show that about 40 percent of non-DOD scientists are engaged in R&D, with the exception of NASA, where the number is closer to 85 percent.

To gain traction on the distribution of government scientists across scientific fields, we categorize, in figure 9.6, the percentage of scientists in five broader areas based on OPM classifications. Around 75 percent of the scientists in the DOD work in engineering, and another 10 percent are in physical sciences, such as chemistry and physics. NASA and Energy exhibit similar patterns of scientific personnel being concentrated in engineering and the

15. The decline in HHS R&D-focused personnel is largely the result of a reclassification of a substantial number of scientists at the NIH between FY2001 and FY2002. This occurred because all scientists hired in the excepted service under Title 42 with pay plan AD were converted from the "Research" to the "Other" functional classification with the implementation of the newly acquired human resources information technology system.

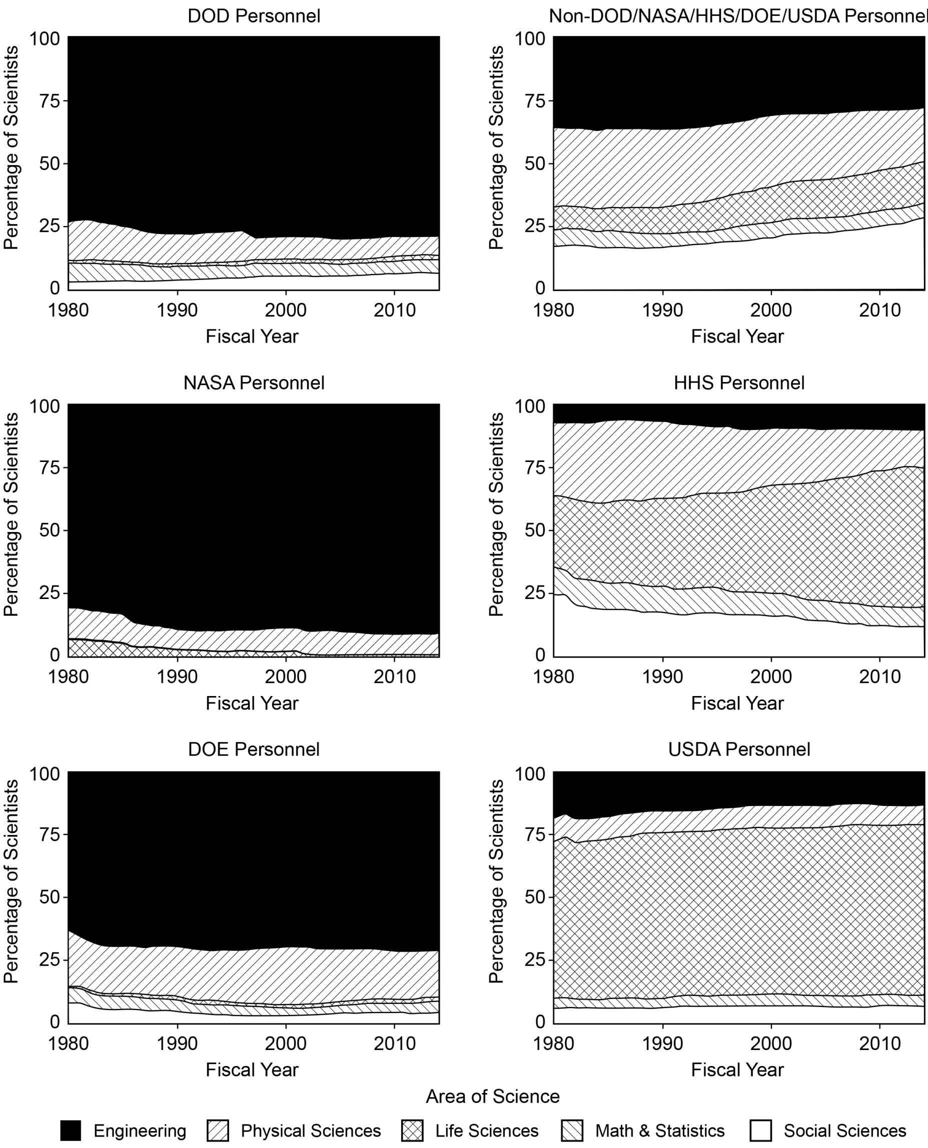

Fig. 9.6 Federal scientists by scientific area, 1980–2014

physical sciences. In contrast, in non-DOD agencies, approximately one quarter of scientists work in engineering and an additional 18 percent in the physical sciences. In the latest years of data, around 30 percent of non-DOD scientists work in social sciences or math and statistics, and an additional 20 percent are in the life sciences. Figure 9.6 also illustrates the concentration of HHS and USDA scientists in the life sciences in conjunction with their health, medical, and agricultural R&D missions, each possessing 56 percent and 68 percent of their scientific workforce in the life sciences, respectively.

We believe there are three takeaway messages from the analysis of federal scientific human capital. First, the nature of innovation being conducted at the DOD is likely very different from that in the non-DOD agencies, based on the composition of its human capital. Second, the DOD is heavily focused on engineering and physical sciences, fields that lend themselves to patenting. Based on the scientific expertise of personnel, non-DOD agencies will tend to innovate in the social sciences, math, statistics, and life sciences. The former three areas do not lend themselves to patenting, and the final area may or may not lend itself to patenting, depending on the nature of the scientific innovation. Our third takeaway is, therefore, that using patents as a measure of innovation in government will tend to overstate the nature of innovations being pursued by the DOD and understate the nature of innovations being conducted by non-DOD agencies, and it will overstate the contribution of the DOD to government innovation (assuming these innovations can be patented without national security concerns) and understate the contribution of the non-DOD agencies to government innovation. These distortions are critical to recognize when analyzing available data for indicators of public-sector innovative success.

9.5 Outputs for Technological Innovation in the Federal Government

The previous sections of this chapter focus on the inputs—human and financial capital—to technological innovation in the government, which are the precursor to government scientific innovation. This section begins by exploring the outputs of technological innovation, beginning with an in-depth analysis of patents followed by a discussion of viable alternative output measures. Although patents are likely to be informative of government technological output, they are unlikely to be comprehensive or necessarily representative measures of the scope, variety, and nature of innovations that occur in the government.

Our analysis of patents is based on US Patent and Trademark Office (USPTO) patent data, which has been processed and made available by PatentsView.org, a collaborative project between USPTO, USDA, the American Institutes for Research, and others.[16] We augment these records with measures made available by the National Bureau of Economic Research (NBER) Patent Data Project.[17]

16. See: www.patentsview.org (last accessed February 29, 2020).

17. See: https://sites.google.com/site/patentdataproject/Home (last accessed February 29, 2020).

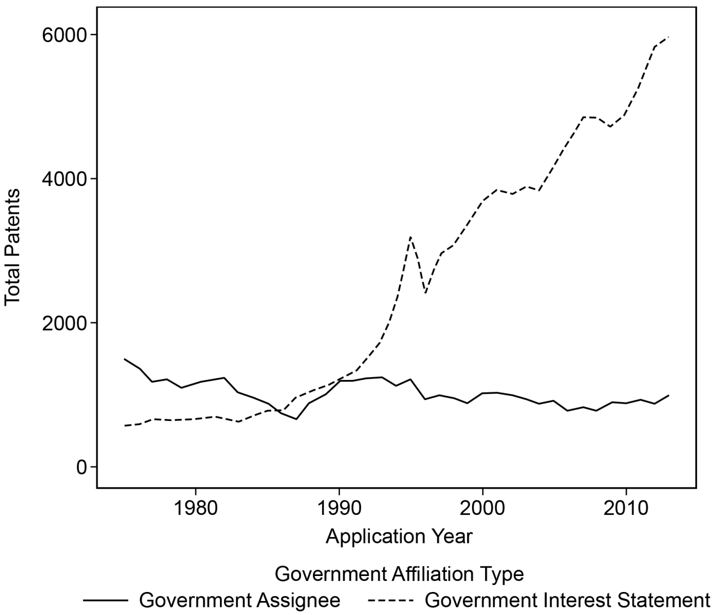

Fig. 9.7 US patents by government assignment and interest, 1975–2013
Note: Data on government affiliation type from PatentsView.org.

9.5.1 Patents

Government involvement in patented innovations takes two primary forms. First, if government scientists create a new invention, the government generally becomes the patent assignee, thereby holding the right to use or license the patented innovation. Second, if the government funds a third party, such as a university, to conduct research leading to a patented innovation, the third party generally takes ownership of the invention and becomes the patent assignee, while the government maintains an "interest" in the patent. That interest is usually composed of a royalty-free license to the invention. All patents generated with government funding are required to report the government's involvement in an interest statement on US patent applications.[18]

Figure 9.7 illustrates the number of US patents in which the government is an assignee and in which the government has an interest. From 1975 to

18. Researchers have found heterogeneity in inventors' disclosure of government interest in their inventions, which may result in underreporting government support for innovation (Rai and Sampat 2012). Patents generated by Cooperative Research and Development Agreements and other scientific procurement mechanisms, especially at the DOD, do not always include an explicit government interest statement or assignment.

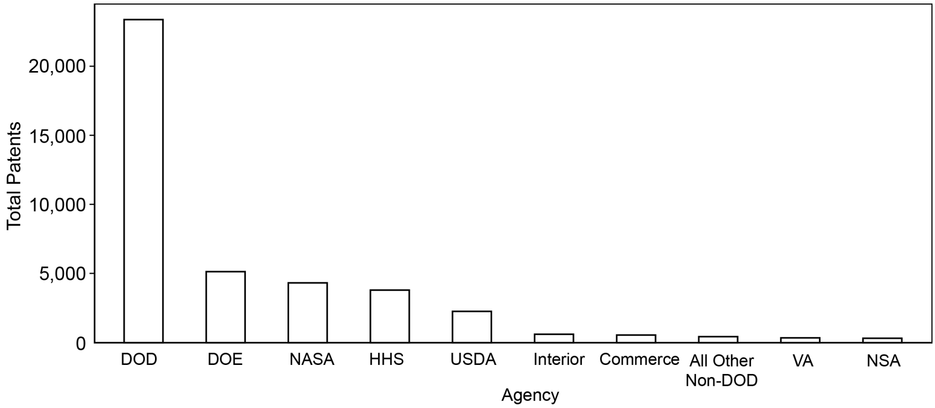

Fig. 9.8a Total patents assigned to government agencies, 1975–2013
Note: Data from PatentsView.org.

2013, the number of government-assigned patents remained relatively stable at about 1,500 patents per year.[19] Despite the stability of the number of government-assigned patents, the number of government interest patents has increased nearly 12-fold during this time, from roughly 500 patents/year to almost 6,000 patents/year. There are many reasons for this substantial increase in government interest patents (which are beyond the scope of this chapter), including increased government extramural innovation funding, the Bayh Dole Act, career concerns for academic scientists, and numerous other factors (Azoulay et al. 2019; Fleming et al. 2019; Hegde and Mowery 2008; Jaffe and Lerner 2001; Owen-Smith and Powell 2001; Popp Berman 2008).

Figures 9.8a and 9.8b illustrate the total number of patents granted during 1975–2013 with either a federal government assignee or government interest statement tied to a federal agency, respectively. The DOD generates, by far, most of the government-assigned patents (figure 9.8a), while HHS generates most of the government-interest patents (figure 9.8b). These patterns comport with the human capital trends highlighted earlier, as government-assigned patents tend to be most focused on engineering and physical science technologies while government-interest patents are more heavily clustered in the life sciences.

Figure 9.9 shows the top five Cooperative Patent Classification (CPC) technological subsections for government-assigned and government-interest

19. To put this number in a comparative perspective, the time series profile of the number of government-assigned patents is comparable to the time series profile of the number of patents assigned to Texas Instruments Incorporated over a similar time period.

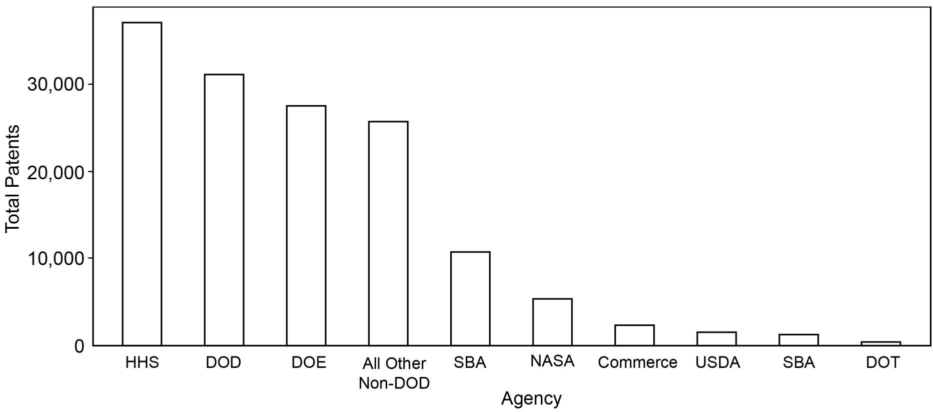

Fig. 9.8b Total patents with government interest statement by agency, 1975–2013
Note: Data from PatentsView.org.

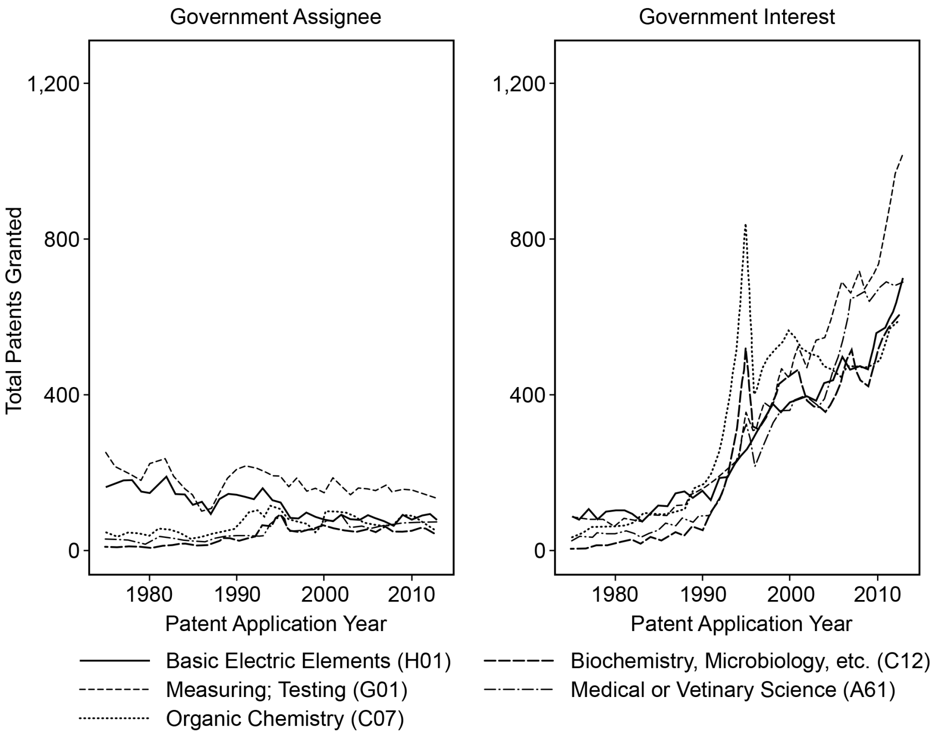

Fig. 9.9 Number of patents granted in government's top six CPC subsections, 1975–2013

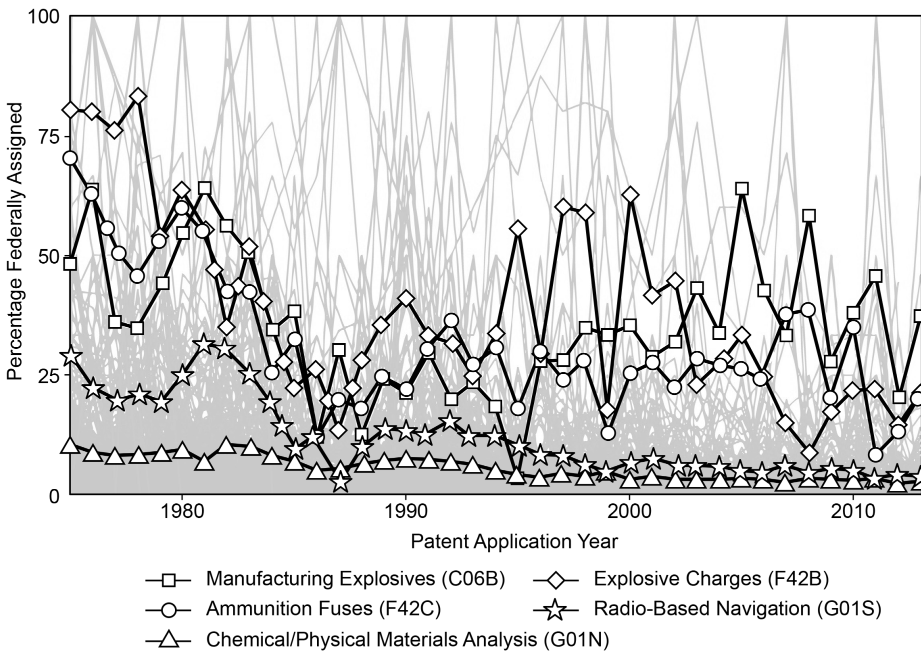

Fig. 9.10 Top CPC patent groups by government assignment, 1975–2013

Note: Top five groups highlighted with highest weighted average percentage; gray lines represent all 631 CPC groups. Denominator is combined patents assigned to US companies and federal government. Annual average weighted by number of federally assigned patents.

patents over nearly 40 years.[20] In addition to the distribution across technologies, we see relative stability in the top CPC subsections for government-assigned patents and the rise of biological and medical-related patents in the government-interest patents.

An alternative way to measure the contribution of government intramural science to technology is to measure the government's patent share in various technological areas. Figure 9.10 shows the share of government-assigned patents relative to all patents from 1975 to 2013 for five CPC groups (tertiary level). These five CPC groups have the highest average weighted percent of

20. The CPC is a classification scheme developed between the USPTO and European Patent Office in an effort to harmonize patent classes around the world. For more, see: https://www.uspto.gov/patents-application-process/patent-search/classification-standards-and-development or https://www.cooperativepatentclassification.org/about (last accessed February 29, 2020). CPC subsections are the second level of specificity in the CPC hierarchy. For example, in the overarching CPC section of "A: Human Necessities" (Level 1), there is a subsection devoted to "A01: Agriculture; Forestry; Animal Husbandry; Hunting; Trapping; Fishing" (Level 2), in which there is a group for patents in "A01D: Harvesting; Mowing" (Level 3). We discuss patents at the second and third levels of the CPC hierarchy (i.e., subsections and groups, following the PatentsView.org labels).

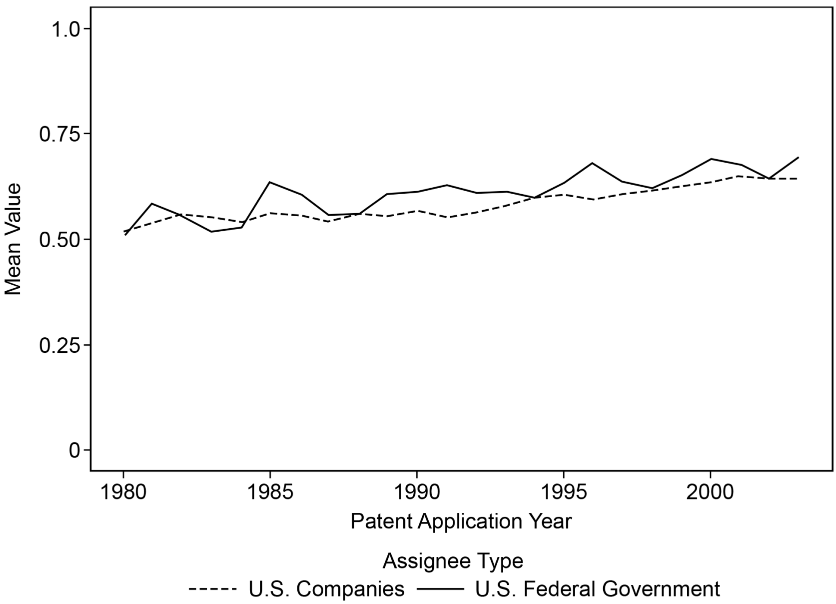

Fig. 9.11a Average patent originality in Measuring; Testing (G01) patents, 1980–2003

Note: Patent citation records from NBER Patent Data Project.

government patents out of all 671 CPC patent groups.[21] Figure 9.10 highlights the five patent groups in which the government has the largest patent share: Manufacturing Explosives, Ammunition Fuses, Explosive Charges, Radio-Based Navigation, and Chemical/Physical Materials Analysis. This heavy patent share in national defense-related technologies is perhaps not surprising, given the technological focus and magnitude of the DOD intramural R&D effort on what are likely patentable technologies.

Having established the focus of government patenting, we now examine the character and quality of the patents generated by the government. The results we present here were determined for each of the top five patent CPC subsections identified in figure 9.9. Because the results are largely similar for all five of these subsections, we present the results only for the top government-assigned subsection, measuring and testing technologies, in figure 9.11a–c.[22]

We begin with an analysis of patent novelty. In this chapter, we employ

21. The weighted average used to determine which CPC groups have the highest concentration of government patents is calculated by multiplying the annual percent of patents in each group assigned to the federal government by the number of government patents in the group, averaged across all years.

22. Results for the remaining CPC subsections are available from the authors.

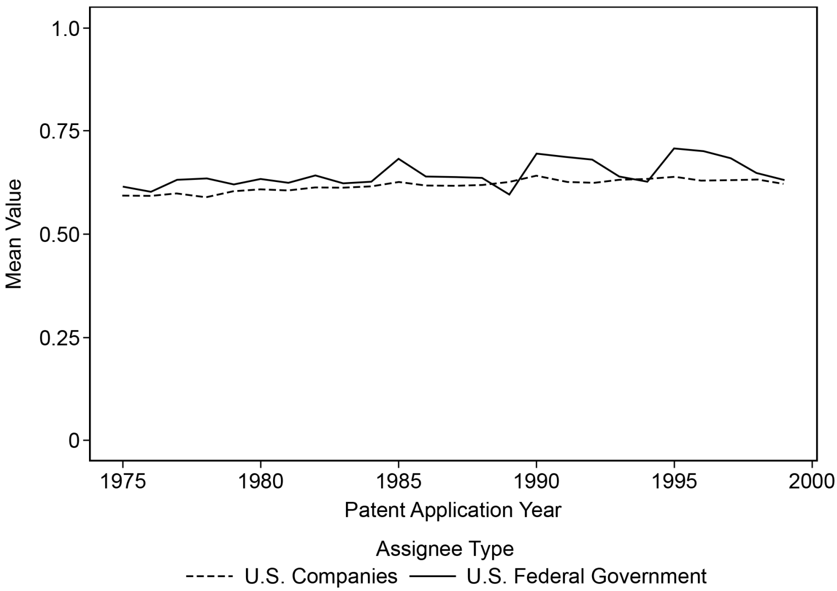

Fig. 9.11b Average patent generality in Measuring; Testing (G01) patents, 1975–1999

Note: Patent citation records from NBER patent Data Project.

two measures of novelty based on the work of Trajtenberg, Henderson, and Jaffe (1997), which have been made available by the NBER Patent Data Project.[23] The first novelty measure we look at considers the *originality* of patents, which is based on the breadth of patents that the focal patent cites.[24] Figure 9.11a presents the results from 1980 to 2003 for patents in the Measuring and Testing technologies subsection, comparing patents assigned to the federal government with those assigned to US companies. It shows that both the government and corporate inventions are, on average, more original over time, but that over almost the entire period, government-assigned patents are slightly more original than the corporate patents in Measuring and Testing.

As a second measure of novelty, we calculate the Trajtenberg, Henderson, and Jaffe (1997) measure of patent *generality*, which is based on the

23. Researchers have also developed alternative measures of patent novelty (Balsmeier et al. 2018; Fleming and Sorenson 2004; Trajtenberg, Henderson, and Jaffe 1997). We use the Trajtenberg et al. measures because of their scope and ready availability through 2003.

24. $originality_{patent} = 1 - \sum_{1}^{C} c_{cited}^{2}$, where c^2 is the squared proportion of patents cited by the focal patent from a single patent class, summed across all classes cited, C. Originality is thus a backward-looking measure of novelty, encompassing the breadth of scientific areas that the focal patent incorporates.

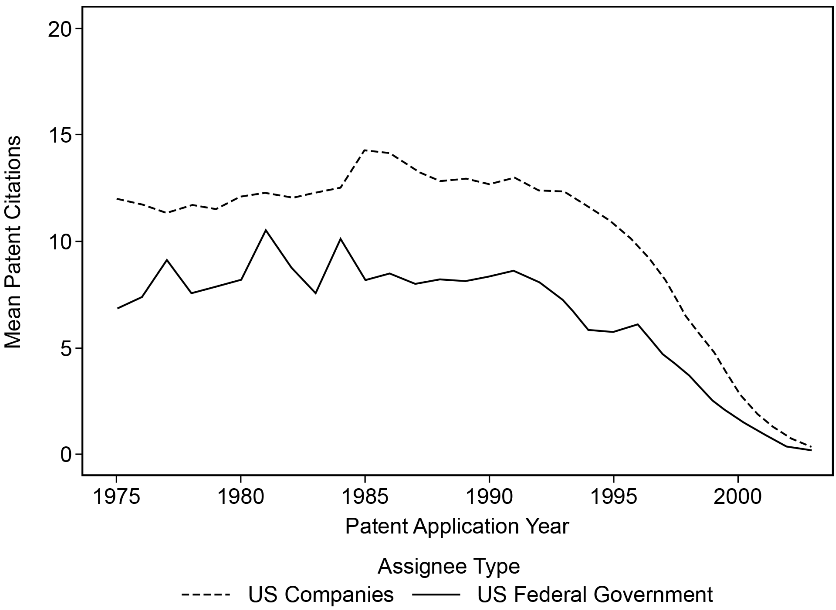

Fig. 9.11c Average patent citations in Measuring; Testing (G01) patents, 1975–2003

Note: Patent citation records from NBER Patent Data Project.

breadth of later patents citing the focal patent.[25] Figure 9.11b illustrates that both groups of patents are, on average, somewhat more general over time, but again, that government-assigned patents are slightly more general than private company patents.

Finally, we examine the citations to Measuring and Testing patents in figure 9.11c. Some authors have referred to patent citations as a measure of patent quality (Henderson, Jaffe, and Trajtenberg 2005; Trajtenberg 1990). Here, there is a noticeable difference between the two sets of patents. The government assigned patents are substantially less often cited than the private company patents in these patent classes, and that pattern persists for the entire time series of the data. In summary, in the five patent classes we examined, we find that relative to private company patents, the government assigned patents are slightly more original, slightly more general, but substantially less cited.

We conduct a similar analysis comparing government interest patents

25. $generality_{patent} = 1 - \sum_1^C c_{citing}^2$, where c^2 is the squared proportion of patents citing the focal patent from a single patent class, summed across all classes citing, C. Generality is a forward-looking measure of novelty, illustrating the degree to which the focal patent is later drawn on by patents in numerous other classes.

Table 9.2 **OLS regression models of patent originality, generality, and citations**

	Patent originality	Patent generality	Patent citations
Assignee type			
Government	0.0484***	0.0462***	−3.3760***
	(0.0025)	(0.0022)	(0.1211)
University	0.0551***	0.0576***	1.8102***
	(0.0018)	(0.0020)	(0.1106)
All others	Reference Category	Reference Category	Reference Category
Grant year FE	Yes	Yes	Yes
CPC group FE	Yes	Yes	Yes
Constant	0.4502***	0.4911***	16.0662***
	(0.0220)	(0.0212)	(0.5415)
Observations	1,733,166	1,460,715	4,646,540
R^2	0.0956	0.1166	0.1216

Notes: Robust standard errors in parentheses. *** $p < .001$.

with private company patents in the same five CPC subsections. These results show a similar pattern in terms of patent novelty: government interest patents are slightly more original and slightly more general than commercial patents without a government interest statement. However, unlike government assigned patents, government-interest-statements patents are not meaningfully less cited than private-sector patents in the same CPC subsections.[26]

While the examples in figure 9.11 are illustrative of areas of heavy government technology focus, there is no a priori assumption that our findings would hold across all scientific areas. To address the question of how general the pattern of greater originality and generality coupled with lower average citations is, we collect all granted patents in the CPC groups for all years when the federal government has at least one patent in a group. We then use ordinary least squares (OLS) regression to estimate three models describing (1) patent originality, (2) patent generality, and (3) patent citations. Each model includes CPC group (third-level specificity) and patent-grant-year fixed effects to control for differences by area of science and period effects, as well as heteroskedasticity-robust standard errors. In addition to accounting for whether a patent is assigned to the federal government, patents are also categorized as university-assigned if the words "college," "university," "regents," or "fellows" appear in the patent assignee name. Table 9.2 presents the results of these three OLS models that are meant to be merely reduced-form descriptions of the data.

Table 9.2 confirms the patterns identified and discussed from figure 9.11.

26. These results are available from the authors.

Government patents, relative to patents assigned to other entities (excluding universities), are more novel as measured by both originality and generality. Furthermore, government-held patents are less cited that patents held by other assignee types.[27] University patents are more original, general, and frequently cited than commercial patents.

In sum, our analysis of patent novelty and impact suggests two distinct results. First, the government appears to be conducting more original and more general science than the private sector. However, the second pattern of lower citations suggests that other inventors are not building on the government's innovations to the same degree that they build on private sector innovations, or alternatively, that the government is innovating in areas that receive less overall innovative attention.

9.5.2 Alternative Measures of Government Innovation

While patents provide a convenient method for examining a slice of technological innovation by the federal government, there are a host of other potential output metrics that could be explored in future research. In this subsection, we discuss these alternative measures.

The first is the use of academic publications by government scientists. For many innovative ideas and inventions, publications embody or precede the innovative contribution, whether it be a contribution to knowledge or a commercial application of an idea. Indeed, publications and citations thereto are already used in the innovation literature as a measure of output (Angrist et al. 2020; Murray and Stern 2007). With respect to government science, publications are likely to be more representative of innovative output relative to patents in many fields, such as economics, sociology, data analytics, mathematics, management, and parts of the life sciences. Indeed, using publications as a measure of government innovative output would likely increase the proportion of government innovation reported by agencies such as the USDA, Commerce, and the EPA and would allow researchers to obtain a more representative picture of government technical output.

A second potential output measure for government innovation is prizes (Jones 2010; Jones and Weinberg 2011). Agencies in the US government award prizes to government scientists and personnel for innovations that enhance efficiency in the governing process and that contribute to knowledge and invention. These prizes can be for individual or team efforts.[28]

27. This result remains consistent when using a negative binomial regression model rather than OLS to estimate the number of citations received. The NBER data containing patent originality and generality measures are based on the USPTO patent class system, not the CPC scheme. Recreating the Trajtenberg, Henderson, and Jaffe (1997) measures with CPC groups replicates the results in table 9.2.

28. There are four types of relevant prizes: individual and group awards, as well as suggestion and invention awards. The former two types distinguish between individual and group efforts, while the latter two distinguish between process improvements and scientific or patentable innovation accomplishments, respectively.

Although prizes cannot be awarded for every innovation, prize data has the advantage of incorporating potentially unobservable information (to the researcher) on the contemporaneous contributions of individuals to innovation in the federal government. While the prize data are not mapped to individual innovations, they are mapped to individual civil servants (Zhang and de Figueiredo 2018), which might also allow researchers to identify "superstar" government innovators and the complementarities and externalities they generate (Zucker and Darby 1996). Likewise, third party prizes, such as the Ash Center prizes for innovativeness in government, might be a vehicle for understanding the contribution of innovations to government efficiency and social welfare.

A third potential method for evaluating the success of government technological innovations is to consider innovations for which the government is a lead user. There is a large literature on user-driven innovation (for a summary, see Franke 2014). Lead users are those who adopt an innovation at the beginning of the innovation's life cycle (von Hippel 1986). Those lead users that stand to capture substantial value from the innovation's success have a high incentive to pursue the innovation themselves (Morrison, Roberts, and von Hippel 2000; Morrison, Roberts, and Midgley 2004). One might rely on this literature to understand when intramural efforts of government innovation are likely to succeed. NASA's development of technologies from rocket propulsion to life-sustaining systems during the Mercury and Apollo programs in the 1960s and 1970s, the government's invention of tabular computing to compile the US Census in the 1940s and 1950s, and the DOD's and NSF's need to connect disparate computing power leading to the Internet are just a handful of examples where the incentives and investments of the US intramural R&D efforts were enhanced because of government as the lead user (Agarwal, Kim, and Moeen 2021; Hacker and Pierson 2016; Mazzucato 2013; Singer 2014).

9.6 State and Local Government Technological Innovation

Throughout this chapter, we have focused on the federal government as the primary public-sector actor in US government technological innovation. However, state-level governments also contribute to intramural R&D efforts. Figure 9.12 illustrates state spending in the seven cumulatively highest-spending states over the decade leading up to 2018 (the faint gray lines in the background of the figure represent the remaining states). New York state spent over $822 million during this period, in 2018 constant dollars, followed by California ($560 million) and Florida ($299 million).

States also indirectly subsidize R&D through many mechanisms. One mechanism is funding the operation of public colleges and universities, which are heavily reliant on state appropriations for their operation. This source

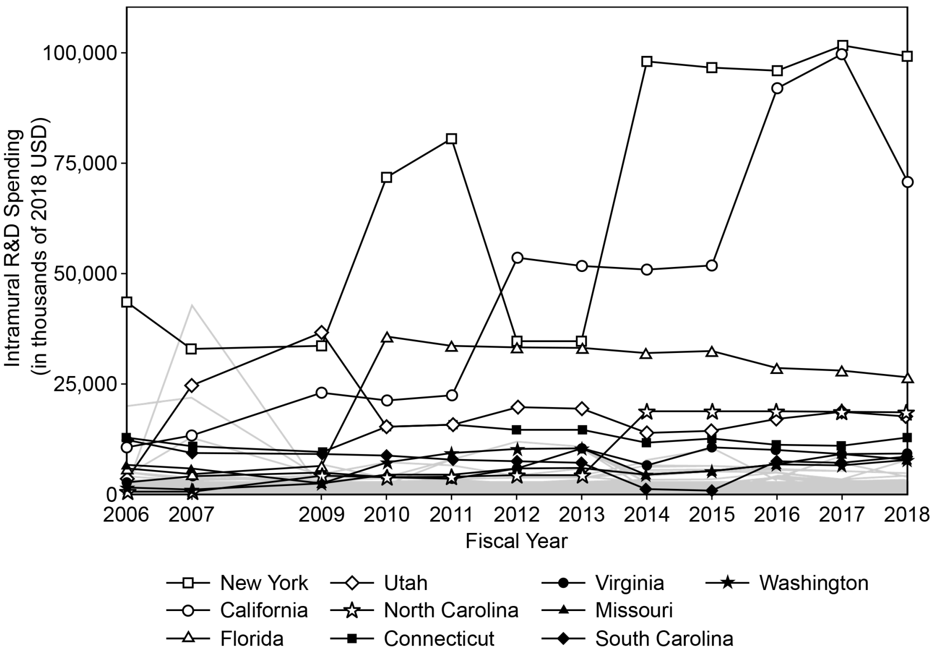

Fig. 9.12 State-level intramural R&D spending, 2006–2018

Source: NSF Survey of State Government Research and Development. Survey not fielded in FY 2008.

Note: Ten highlighted states had the most cumulative spending over the survey period.

of funding declined precipitously after the Great Recession. Although it has been rising since its nadir in 2013, it still remains below pre-recession levels in most states.[29] A second mechanism is through policies, subsidies, and regulations that attract extramural R&D. These and other mechanisms are worthy of further analysis and research.

9.7 Conclusion

Nearly all of the literature on government's role in innovation focuses on either the allocation and productivity of government funds directed to third party research or on various government policies that will enhance private

29. In its 2018 higher education finance report, the State Higher Education Executive Officers Association compared multiple measures of state support for college and university operations, such as per capita spending and allocations as a percentage of state tax revenue. Across multiple measures, nearly all states showed considerable reductions in higher education funding when comparing 2008 to 2016. Report available at: https://sheeo.org/wp-content/uploads/2019/04/SHEEO_SHEF_FY18_Report-2.pdf.

and nonprofit sectors' innovative effort. This chapter examines the nature of intramural government research—the inputs and outputs of government scientists and funding for internal innovation. We believe this analysis of government intramural innovative inputs and outputs is one of the first comparative analyses of the intramural-to-extramural research efforts.

The chapter develops a classification system of innovation in the government, identifying four major types of public-sector innovations: technological, organizational, regulatory, and policy. It is inherently difficult to measure government innovation, because a substantial amount of such innovation occurs in the latter three categories. Therefore, studies that attempt to measure the full government innovative effort are likely to miss much of the nontechnological innovation that occurs in the federal government. We believe that a more robust and comprehensive innovation measurement system is needed to capture the full innovative output of the federal government.

When constraining the analysis to only government technological innovation, we see that inputs (scientists and funding) are heavily weighted toward the DOD, NASA, and DOE. Not surprisingly, output-oriented measures of innovation, such as patents, are also heavily weighted toward these agencies because of the scientific disciplines from which they draw: engineering, the physical sciences, and some parts of the life sciences. Patents will tend to miss innovations in agencies that rely on data analytics, social science, mathematics, and other parts of the life sciences. Thus, patents will give a biased view of the composition of technological innovation in the government. Despite this, the patents that are generated by government scientists are slightly more original, slightly more general, but much less cited than those of the private sector.

One strong trend in the data is that while the amount of government funding for R&D has increased substantially over the past few decades, the number of government scientists has remained relatively stable. The government has shifted toward a more extramural science orientation. This policy may be beneficial if policymakers believe that it enhances the innovativeness and diversity of ideas and inventions, creates more efficient discovery and commercialization, or supports a broader scientific infrastructure of the country. However, these advantages will be mitigated if excessively outsourcing science diminishes the capability of the government to conduct some necessary intramural research, to monitor extramural research, to overcome market failure in the private markets for research, or to develop a socially optimal scientific infrastructure.

Overall, this chapter is only an initial look at the US government's intramural science efforts. It is meant to provide an opening into new research in this field, which could be more fully understood and better mapped. This work attempts to provide a base for future research to understand the role of government innovation and entrepreneurship in economic growth.

Appendix

Table 9.A.1 Data sources

Data	Source	Description	Years covered
Innovations in American Government Awards	Harvard Kennedy School Ash Center for Democratic Governance and Innovation	Annual award data on Ash Center's Innovation in American Government Award	1995–1999
Federal Employment Records	Office of Personnel Management (OPM) Central Personnel Data File	Database contains annual employment records for almost all non-national security government employees, including occupation and scientific role, if applicable	1980–2014
Federal R&D Spending by Agency	National Science Foundation (NSF)	Annual R&D spending by government entity, compiled by the NSF using the Survey of Federal Funds for Research and Development	1967–2018
Federal R&D Spending by Performer	National Science Foundation (NSF)	Annual R&D spending allocated to organizations in and outside the federal government, compiled by the NSF using the Survey of Federal Funds for Research and Development	1967–2018
US Patent Records	PatentsView.org	Open-source patent database containing US Patent and Trademark Office-granted patents, supported by USPTO Office of the Chief Economist	1976–2013
US Patent Novelty & Citations	NBER Patent Data Project	Public data files containing originality and generality scores for US patents granted during 1976–2006, based on Trajtenberg, Henderson, and Jaffe (1997); and patent-to-patent citations	1976–2006
State R&D Spending	NSF Survey of State R&D Expenditures	Periodic survey conducted by NSF and US Census Bureau to collect data on state-level R&D spending	2006–2007, 2009–2018

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Introduction

Ever since Vannevar Bush's groundbreaking report to President Franklin D. Roosevelt, "Science—The Endless Frontier" (Bush 1945), the US government has played an increasingly prominent role in the realm of research and development (R&D) and innovation. This includes funding of research through the National Science Foundation and the National Institutes of Health (NIH); mission-oriented research in defense, space, and energy; support of commercial R&D by small and medium-size businesses through the SBIR and STTR programs, and the like.

However, the impact of government on innovation goes much further, reflecting the size of government in the economy,[1] procurement policies, the impact of taxation, and the deliberate or unintended effects of regulation. Thus, for example, setting standards for fuel economy or energy conserva-

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1. The average government/GDP ratio for 36 OECD countries stands now at 43 percent, with the US being at the lower end with 38 percent.