Federal R&D Budget Trends: A Short Summary

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At its best, public research forms an ecosystem with universities and industry, contributing to progress in pharmaceuticals, semiconductors, food, aerospace, and other sectors.

Why Does the Federal Government Fund R&D?

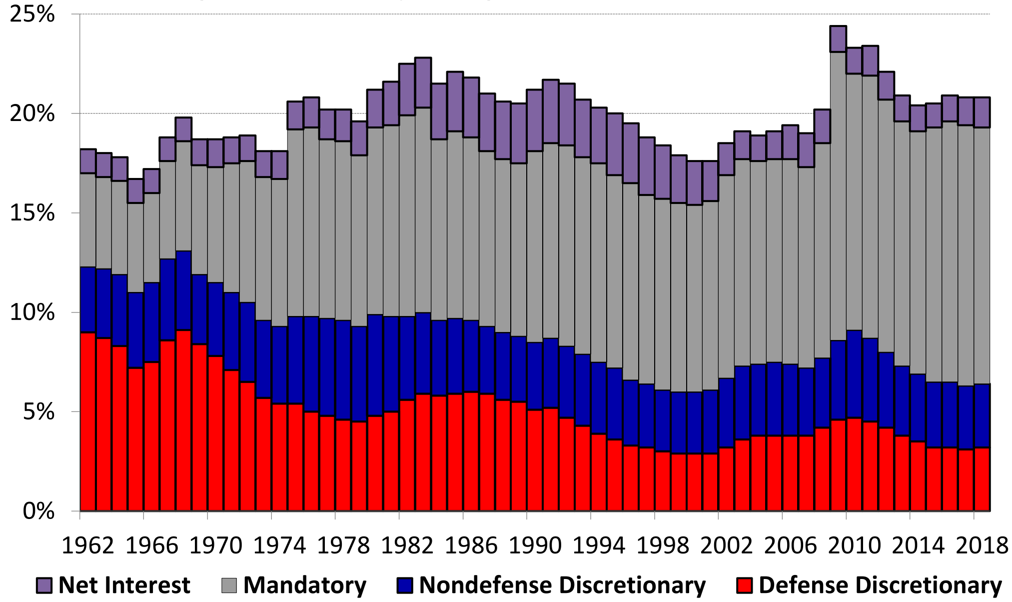
Government has historically had a major hand in scientific research and technology development. Agencies' engagement with science and technology is, of course, critical for achieving public missions in national security, agriculture, infectious disease response, infrastructure, and other areas. But economic theory also points to broader reasons for public investment in research. It is difficult for firms who invest in knowledge creation to capture *all* the economic benefits of that knowledge: firms can acquire and apply knowledge created by others, without having to invest the initial resources to produce it. Research is risky, with uncertain prospects for success, and requiring long-term commitments of funds, personnel, and infrastructure.

These qualities, coupled with competitive pressures in modern markets, can lead to research underinvestment by private sources. As economist Joseph Stiglitz has written, "Knowledge can be viewed as a public good, and the private provision of a public good is essentially never optimal."[1] This is one reason why industrial R&D tends to be increasingly focused on shorter-term, lower-risk development: nearly 80 cents of every dollar spent by industry on R&D is now ticketed for development, compared with 20 cents for basic and applied research. As one analyst has written, "Market-driven R&D has shifted the focus from fundamental research toward applied R&D…Now, companies are cutting down on long-term and risky endeavors."[2]

On the other hand, such endeavors are in the wheelhouse for federal R&D, especially among non-defense agencies like the National Science Foundation, the National Institute of Standards and Technology, or the National Institutes of Health. As a 2014 National Academies panel on the American research enterprise argued, "Increasingly, government is called upon to fund high-risk, long-term research and some types of applied research, particularly proof-of-concept research, at least to the point where the risks of investment in such research are reduced to attract private-sector funding."[3] For instance, a Government Accountability Office study of the Advanced Research Projects Agency-Energy (ARPA-E), within the Energy Department, found that the agency invests in technology still too risky for even venture capital.[4] The risk orientation of federal R&D is apparent in technology outcomes, as federally-funded university research has been associated with more radically disruptive breakthroughs.[5]

In this sense, the public research and technology enterprise lays a foundation of knowledge, tools, and a skilled workforce. At its best, it forms an ecosystem with universities and industry, contributing to progress in pharmaceuticals, semiconductors, food, aerospace, and other sectors through

Figure 1: Federal Spending as a Percent of GDP Since 1962



Source: Budget of the U.S. Government FY 2019. © 2018 AAAS

research output, human capital, and instrumentation.[6] And with the globalization of science and the rise of R&D in East Asia, such public-private interaction will likely become more important over time from a competitiveness perspective.

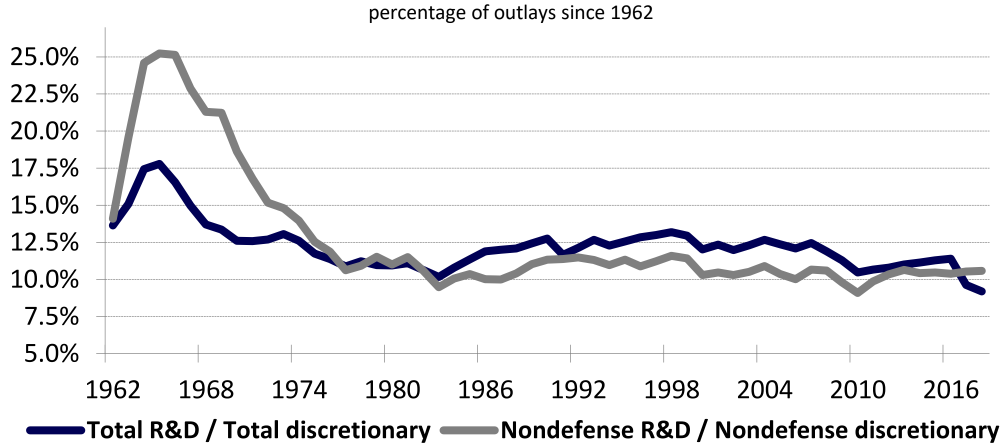
Discretionary Spending is Important Context for R&D

Virtually all federal R&D funding is contained within the discretionary budget, the portion of federal outlays determined annually through the appropriations process. As seen in Figure 1, discretionary spending – especially defense – once occupied a more prominent place in the budget. Over time, however, the budget has come to be dominated by *mandatory* spending, made up mostly of the major entitlement programs – Social Security, Medicare, and Medicaid – and mostly on autopilot. This is driven by an aging population, rising healthcare costs, and other factors.

This matters for science because R&D doesn't tend to change much as a share of the discretionary budget. At the height of the Space Race, R&D comprised 17.4 percent of discretionary spending, as seen in Figure 2. But since

Figure 2: R&D as Percent of Discretionary Spending

percentage of outlays since 1962



Source: Budget of the U.S. Government FY 2019. © 2018 AAAS

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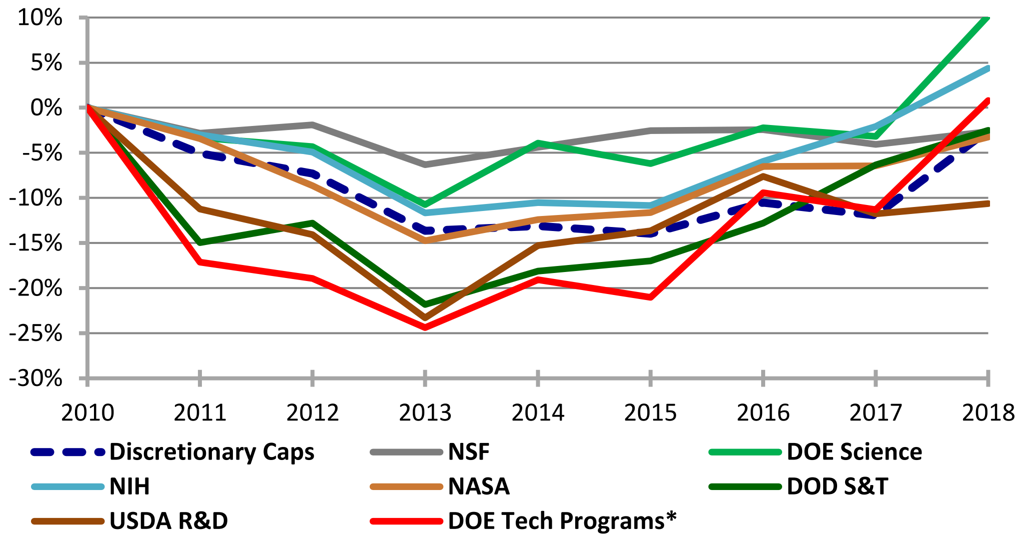
Figure 3: Federal S&T Agency Spending Since FY 2010

Percent change in discretionary budgets from FY10 levels, constant dollars



*Including nuclear, fossil, grid research, renewables, and efficiency.

Based on AAAS analyses of historical OMB , agency, and appropriations data. © 2018 AAAS

In many years, as the discretionary budget goes, so goes the R&D budget.

the early 1980s, R&D has tended to fluctuate between 11 and 13 percent of discretionary spending (recent changes in what gets counted as R&D have pushed this share somewhat lower). In many years, as the discretionary budget goes, so goes the R&D budget.

The centrality of discretionary spending for science can be seen in spending changes by agency (Figure 3). Beginning in FY 2011, the base discretionary budget began coming down, first for nondefense and then defense as well. The spending caps established by the Budget Control Act of 2011, including sequestration in FY 2013, intensified the strain. The impact on science agency budgets is plain in Figure 3, with budgets moving in rough unison depending on what is happening with the broader discretionary budget. This has historically been the case, though basic science funders tend to do a bit better than applied science funders.

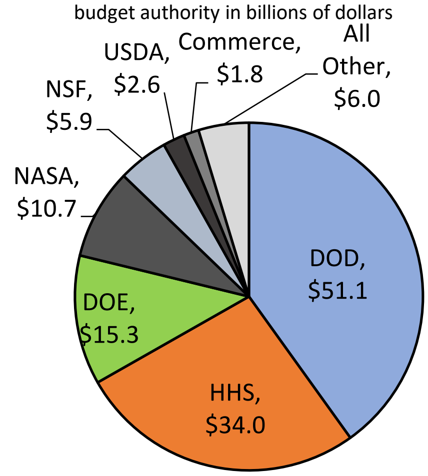
In the long run, the Congressional Budget Office (CBO) predicts discretionary spending will continue to decline relative to the federal budget and the economy overall as mandatory spending continues its growth.[7] This suggests federal R&D activities may also continue to decline relative to other economic activity, even as federal R&D dollars grow in absolute terms.

Major Recent Trends

In FY 2017 (the most recent year for which official figures are available at the time of this writing), federal R&D reached $127.3 billion; the distribution is shown in Figure 4. This distribution

Figure 4: R&D in FY 2017

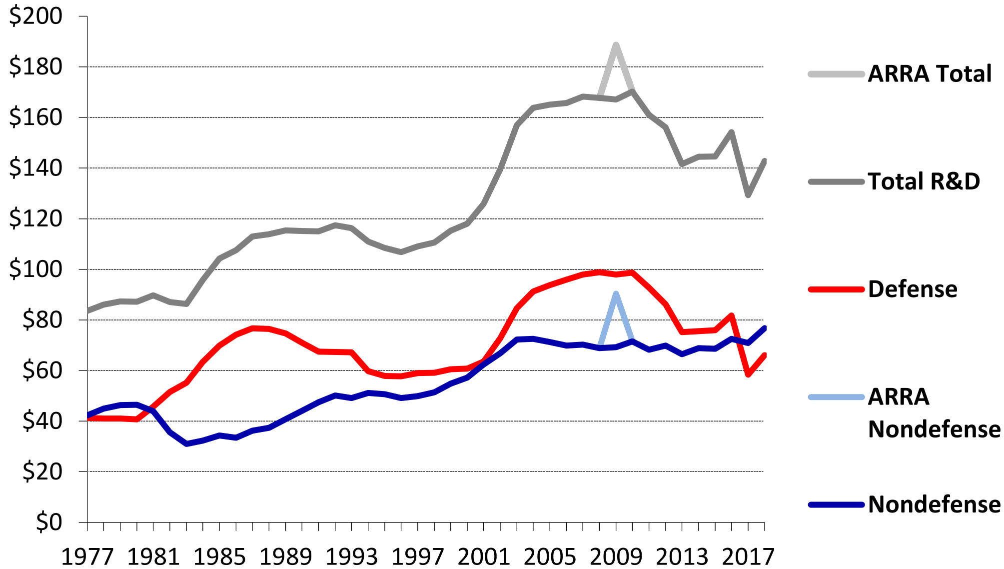
budget authority in billions of dollars



Estimates based on agency and OMB data. R&D includes conduct of R&D and facilities. © 2018 AAAS

Figure 5: Federal R&D Since 1977

billions of constant 2018 dollars



Source: Up to 1994: NSF Federal Funds survey. 1995 to Present: AAAS analysis of agency budget data. © 2018 AAAS

doesn't tend to change radically from one year to the next. However, note that OMB recently adopted a new definition of R&D that narrows what is counted as "development." The result is that spending labeled "R&D" has been reduced for NASA and, especially, DOD, though funding for the underlying activities has not changed. [8] The effect of these accounting changes is visible in the most recent two years in Figure 5.

The past 20 years of federal R&D appropriations can be divided into four rough phases. In the first phase, from FY 1997 to FY 2004, federal R&D funding increased rapidly, by 44.0 percent. This rise was driven partly by increased defense R&D following the September 11 attacks, but especially by the Congressional effort to double the National Institutes of Health (NIH) budget. Other agencies like the National Science Foundation (NSF) and the Office of Science within the Department of Energy (DOE) also experienced some funding growth in this period.

The second phase ran from FY 2004 to about FY 2010 and mostly represents a plateau. Defense R&D remained elevated, while the picture was more complicated for nondefense agencies. Funding did increase for some like NSF, DOE Science, and the National Institute of Standards and Technology (NIST), all of which were prioritized for budget doubling by the Bush Administration and the America COMPETES Act legislation.[9] But this was offset by erosion of the NIH budget as appropriations failed to keep pace with inflation. The end of this second phase was punctuated by the generous but one-time funding boost in the American Recovery and Reinvestment Act (ARRA), which added over $18 billion in nominal dollars in FY 2009, along with transiently generous annual appropriations in FY 2009 and FY 2010.

After FY 2010, funding entered a brief but jagged third phase of decline. As mentioned above, discretionary spending was cut dramatically over the FY 2010 to FY 2013 period, partly in

OMB's R&D Definitions

"Basic research is defined as systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. Basic research, however, may include activities with broad applications in mind."

"**Applied research** is defined as systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met."

"**Development** is defined as systematic application of knowledge or understanding, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements."

R&D facilities spending "includes the acquisition, design, and construction of, or major repairs or alterations to, all physical facilities for use in R&D activities. Facilities include land, buildings, and fixed capital equipment, regardless of whether the facilities are to be used by the Government or by a private organization, and regardless of where title to the property may rest. Includes fixed facilities such as reactors, wind tunnels, and particle accelerators."

Lastly, **R&D equipment** spending "includes acquisition or design and production of movable equipment, such as spectrometers, research satellites, detectors, and other instruments."

Source: OMB Circular A-11, Sec. 84

reaction to the large deficits incurred during the financial crisis. These cuts, concurrent with a drawdown in war funding, resulted in substantially reduced R&D spending within defense and nondefense agencies, notwithstanding Obama Administration preferences. Note that accounting changes within DOE and NASA in those years make nondefense R&D appear to follow a steadier path than it did in reality, when agency budgets were being cut as seen in Figure 3.

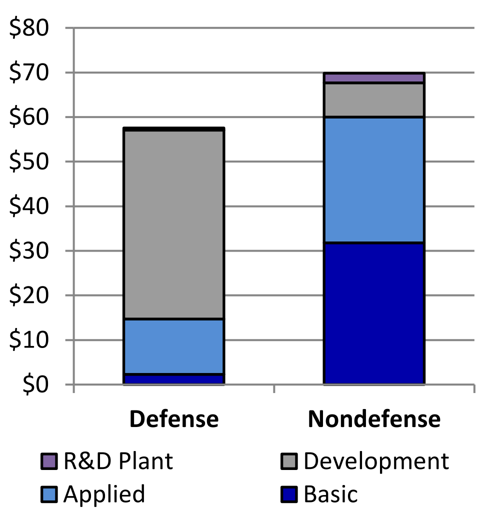
Phase four is the most recent, with multiple deals to raise discretionary spending underlying multiple large increases for science agency budgets, often with bipartisan support. For instance, science and technology appropriations in FY 2018 were the most generous in a decade and a half.[10]

R&D by Character

R&D budget data is recorded by federal agencies in five categories: basic research, applied research, development, facilities, and equipment (the latter two are combined as "R&D plant"). The definitions for these activities are provided in OMB Circular A-11, Section 84 (see box, this page).[11] Agencies do their best to accurately and consistently apply these definitions, but there will always be a level of subjectivity, especially between basic and applied research, and definitions can change over time – as with the recent narrowing of the definition of "development" mentioned above. Indeed, the idea of jettisoning the entire basic/applied dichotomy has its proponents.[12]

Figure 6: R&D by Character

FY 2017 budget authority in billions



Source: OMB and agency R&D data. © 2018 AAAS

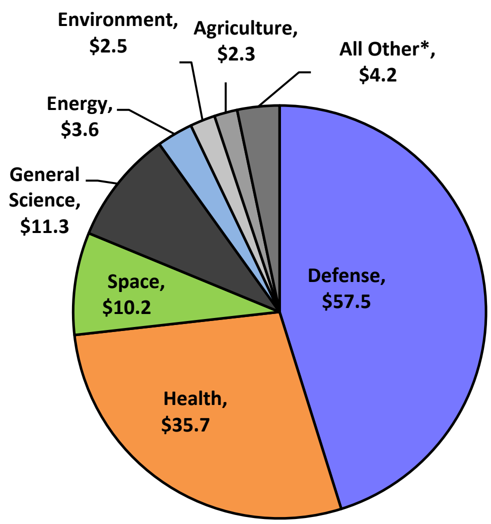
Different parts of the federal R&D enterprise focus on different classes of R&D. Generally, basic and applied research is funded by nondefense agencies like NIH or NSF, focused primarily on more radical or fundamental knowledge creation. Development is mostly funded by the Department of Defense (DOD) as part of its full-spectrum technology acquisition pipeline, from knowledge creation to fabrication and procurement. There are exceptions to this division, however: NASA funds extensive technology development as part of its exploration mission, while DOD maintains a sizable research enterprise through the military labs and through agencies like DARPA.

Federal R&D by Function

Budget functions are the 20 or so official categories used to classify all government outlays. While most functions have some R&D spending, R&D is mostly concentrated in three: Defense, Health, and General Science, Space, and Technology (many analyses, including AAAS data, split this last function into its two component subfunctions, "General Science" and "Space." The Energy, Natural Resources and Environment, and Agriculture functions typically contain R&D of

Figure 7: R&D by Function

FY 2017 budget authority in billions



*Includes Transportation, Commerce, Justice, and others.
Source: OMB R&D data, agency budget justifications, and other agency budget documents and data. © 2018 AAAS

around two to three billion dollars each. R&D spending in the Transportation, Commerce, Veterans, and Justice functions are also substantial.

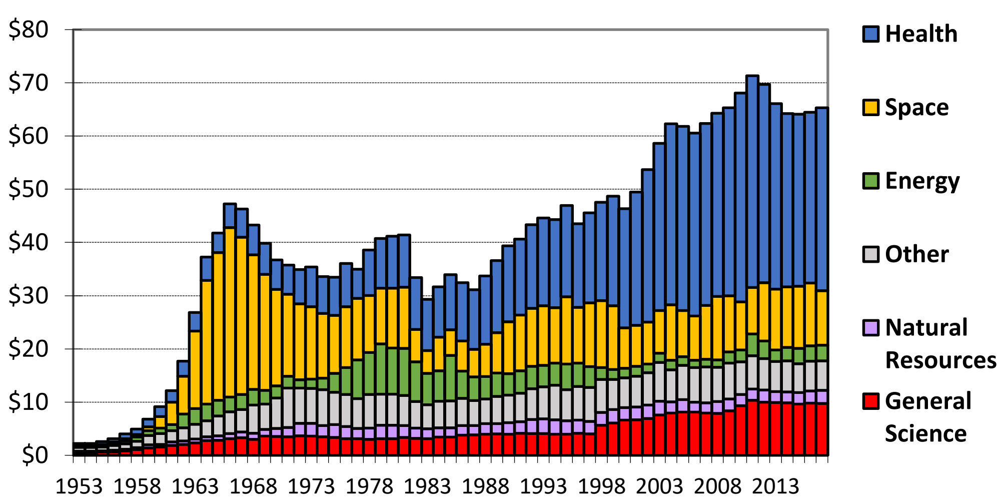
Comparing across functions can indicate changing priorities for Congress and the executive branch. Figure 8, drawn from historical data provided by the Office of Management and Budget (OMB), shows such changes since 1953. During the Space Race, R&D in the Space subfunction soared and then retracted following the successes of the Apollo program. Later, the energy crises of the 1970s prompted a temporary increase in R&D for energy technologies. More recently, the health concerns of a prosperous but aging population have made health R&D the primary nondefense function for R&D. The General Science function, primarily basic research programs, has seen fairly steady increases over the decades.

As Share of the U.S. Economy: Development Declining, Research Sustained

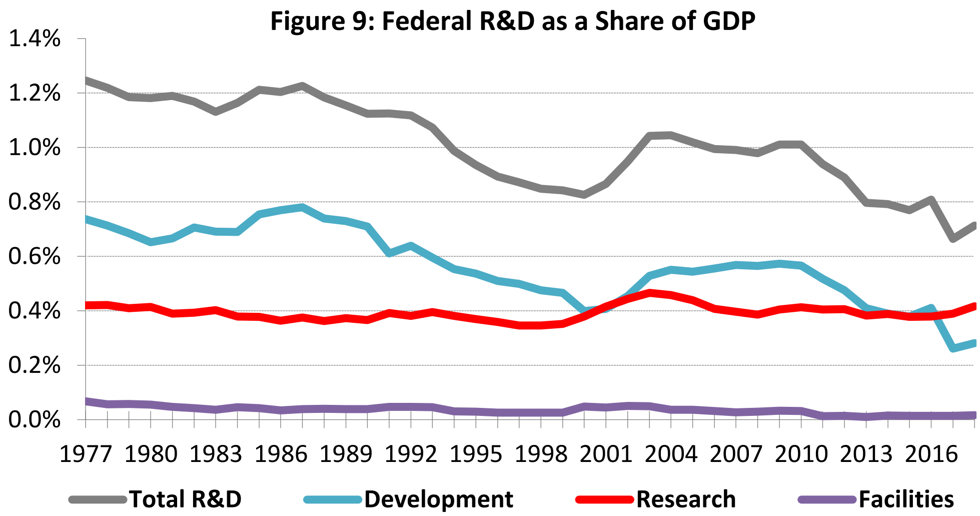
R&D as a share of gross domestic product (GDP), or "R&D intensity," is not definitive, but nevertheless a common metric of a nation's innovative capacity. Figure 9 uses R&D budget authority data, compiled by AAAS since the 1970s, and GDP data from OMB to show federal R&D as a share of U.S. GDP. Clearly, the overall trend has been downward. As of FY 2016 – before the new narrower definition of "development" took effect – the federal R&D budget had declined to an estimated 0.81 percent of GDP, well

Figure 8: Trends in Nondefense R&D by Function

outlays for the conduct of R&D, billions of constant FY 2018 dollars



Source: AAAS, based on OMB Historical Tables in FY 2019 budget. Some Energy programs shifted to General Science beginning in FY 1998. © 2018 AAAS



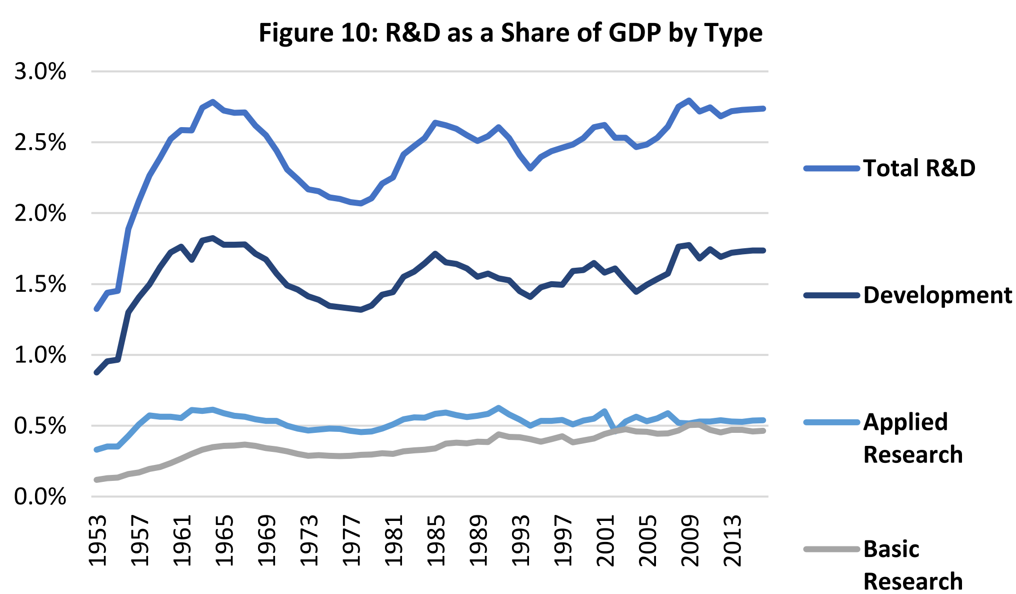
AAAS estimates based on historical agency and OMB budget data. © 2018 AAAS

below earlier levels. This decline is likely to continue as discretionary spending continues to shrink.

As can be seen, however, research spending has remained far steadier as a share of GDP, likely due in part to a more stable nondefense budget – the primary source of basic and applied research dollars. The trend has been somewhat more negative since the end of the NIH doubling in FY 2003, and pressures on the discretionary budget will likely pose a greater challenge to this spending going forward.

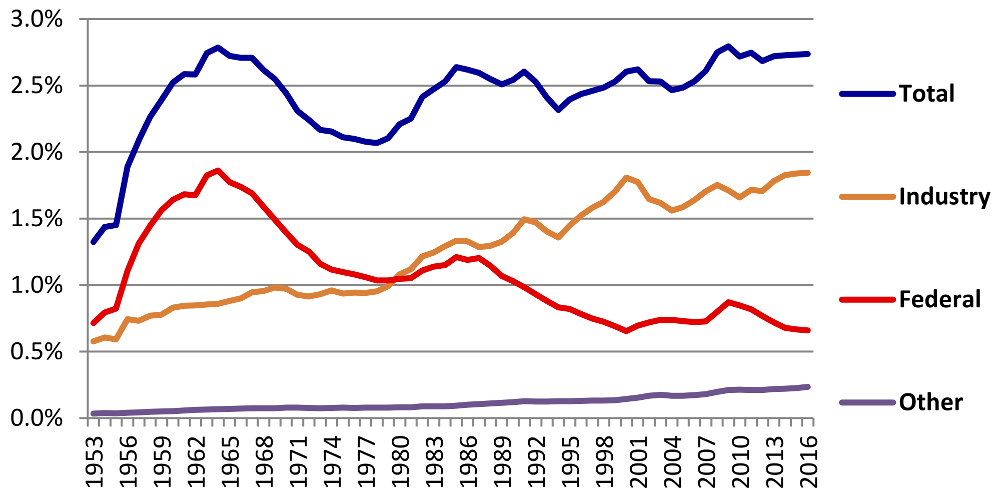
Conversely, development spending has seen greater decline relative to GDP.

While federal R&D intensity relative to GDP has come down, it has been more than offset by increasing contributions from industry, universities, state governments, and private nonprofit foundations. Industry now accounts for the vast majority of U.S. R&D. Figure 10 shows the big picture since 1953; note that data in this section comes from surveys administered by NSF's National Center for Science and Engineering Statistics (NCSES).



Source: National Science Foundation, *National Patterns of R&D Resources* series. © 2018 AAAS

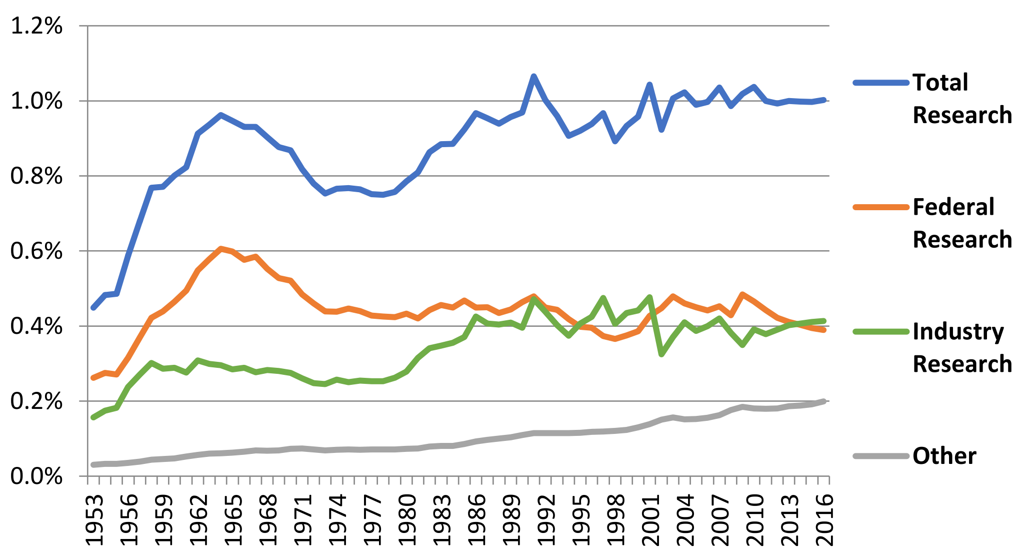
Figure 11: R&D as a Share of GDP by Funder



Source: National Science Foundation, *National Patterns of R&D Resources* series. © 2018 AAAS

Interestingly, the character of the national R&D enterprise hasn't changed much even as government and industry funding has flipped (Figure 11). Basic research, applied research, and development have all held steady or grown as a share of the economy, according to NSF surveys. As mentioned above, federal research spending has remained fairly steady in light of declines in development. At the same time, industrial research spending has caught up, while other sources – especially universities – have also increased their expenditures on research (Figure 12).

Figure 12: Research as a Share of GDP by Funder



Source: National Science Foundation, *National Patterns of R&D Resources* series. © 2018 AAAS

Performers: Universities Increasing; Declines for Industry, Intramural

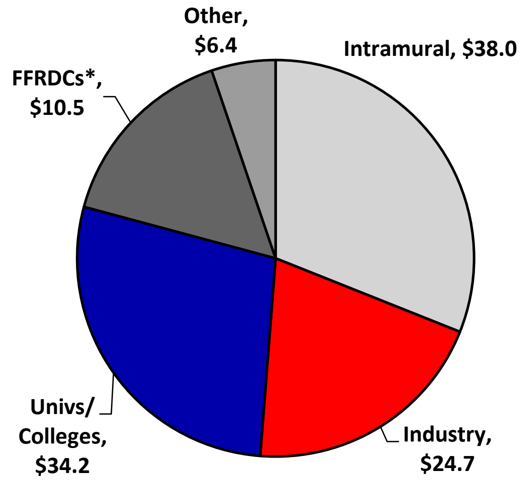
Federally-funded R&D is conducted by a range of performers. Figure 13 shows the distribution of research and development by performer as of 2016, the most recent year of data available in the NCSES *National Patterns of R&D Resources* survey.[13] The figure includes basic research, applied research, and development, but not R&D plant.

As can be seen, intramural government researchers and universities both accounted for similar shares of the federally-funded R&D portfolio, 31 percent and 28 percent, respectively. Industry R&D made up 20 percent, while federally funded R&D centers (FFRDCs), which includes the U.S. national laboratories and other public-private research consortia, accounted for 15.5 percent. The "Other" category is primarily nonprofit research institutes.

While most agencies offer a mixed funding profile, they also have clear tendencies regarding performers. DOD R&D reflects industrial contractors who handle its technology development work, though DOD also maintains an extensive intramural research enterprise and remains a major university research funder, behind only NIH and NSF. NIH also maintains significant intramural research capacity, though the vast majority of its research dollars are sent outside the agency.

Figure 13: Federal R&D by Performer, FY 2016

obligations in billions

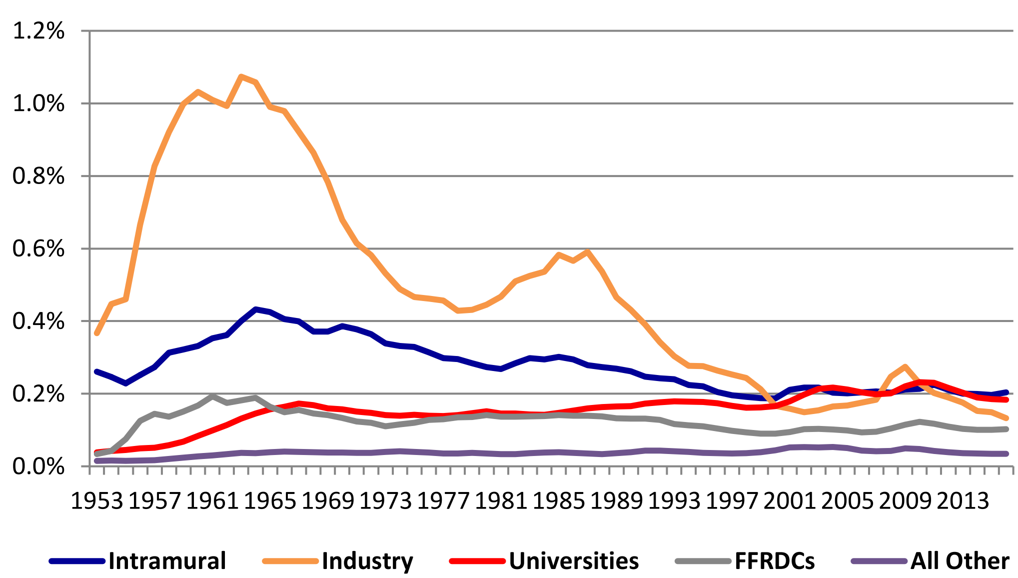


* Federally funded R&D centers: government-owned, contractor-operated laboratories. Source: National Science Foundation, *National Patterns of R&D Resources.* Figures are preliminary. © 2018 AAAS

The only performers of federally-funded R&D to have exhibited collective long-run growth relative to GDP are the nation's universities, mostly through basic and applied research expenditures.

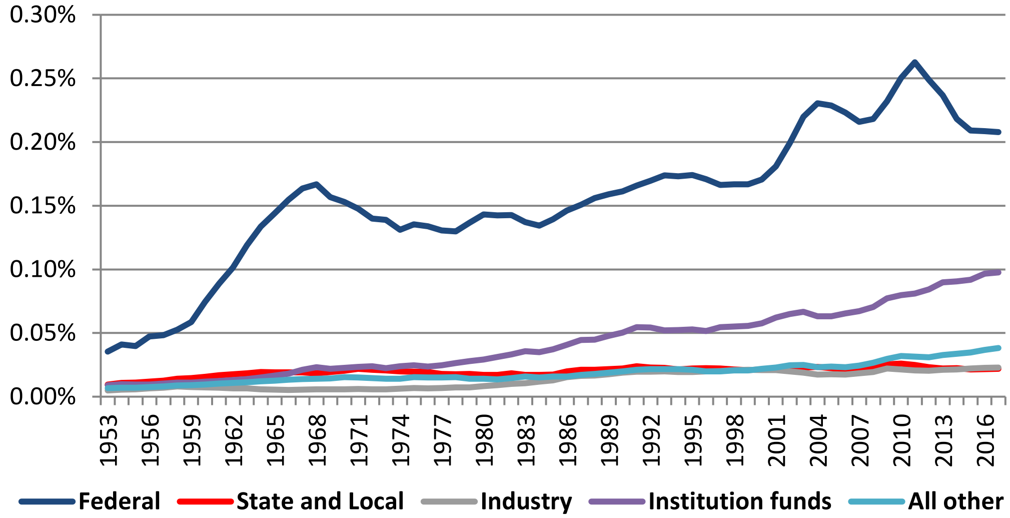
While federal funding of university R&D has notably increased, university self-funding of R&D is also a growing trend.

Figure 14: Federal R&D as a Share of GDP by Performer



Source: National Science Foundation, *National Patterns of R&D Resources* series. © 2018 AAAS

Figure 15: University R&D Funding by Source
As a Share of U.S. GDP



Source: NSF, Higher Education R&D survey series. Includes Recovery Act funding. © 2018 AAAS

DOE channels the largest portion of its funding through the FFRDCs for both defense and civil science and technology work, while NASA's largest expenditures are for industry-performed R&D in the aerospace sector.

From a historical perspective, federal R&D performed by industry saw significant increases around the time of the Space Race, then experienced a smaller spike during the Reagan defense R&D buildup in the 1980s (see Figure 14, which presents spending data as a share of U.S. GDP). Federal intramural R&D has seen a more gradual decline since the Space Race, while R&D performance by FFRDCs and "other" performers has been fairly steady relative to GDP.

The only performers of federally-funded R&D to have exhibited collective long-run growth relative to GDP are the nation's universities, mostly through basic and applied research expenditures. Figure 15, assembled using data from NSF's Higher Education R&D survey, shows trends in university R&D by funder. Note the rightmost peak in federal funding reflects Recovery Act spending.

While federal funding of university R&D has notably increased, university self-funding of R&D is also a growing trend. During the Space Race, the federal government regularly accounted for over 70 percent of university R&D expenditures. Today the federal share has dropped somewhat below 60 percent. At the same time, university spending on research has increased from less than ten percent during the Space Race, to 25 percent and rising today. This means the overall pool of university-performed R&D is rising marginally faster than federal expenditures alone, and suggests the demand for university R&D dollars is outpacing the federal supply. Industry contributions to university research have also increased over this time, though gradually.

Global Landscape: R&D Shifting East

While this review is primarily focused on US trends, it is worth bearing the international context in mind. Global spending on R&D is on a rapid upward trajectory. Total worldwide R&D has roughly doubled since 2000, reaching an estimated $1.9 trillion in 2016.[14]

While the United States remains the single largest funder of R&D, investments continue to shift east. Within the OECD data set, the United States accounted for 39 percent of global R&D in 2000 but only 28 percent in 2016. The E.U. showed a somewhat smaller decline, from 28 percent to 21.5 percent. Meanwhile, the five East Asian economies included in the set – China, Singapore, Taiwan, Japan, and South Korea – collectively increased their share of R&D from 23.4 percent in 2000 to 41 percent in 2016. China has been the major driver in this growth, but three of the other four, excluding Japan, have also grown rapidly (see box). The U.S. National Science Board projects that China will surpass the United States in total R&D funding from all sources by the start of 2019 (see Figure 16).[15]

Examining the trends in research intensity – which, again, refers to R&D as a share of GDP – the gradual shift in R&D resources from west to east is also apparent (see Figure 17, following page). Since 1995, South Korea and Taiwan have nearly doubled their research intensity ratios, while China's has more than tripled during this time. Meanwhile, the U.S. has slipped to tenth place overall, falling behind Germany, Taiwan and South Korea. This comes amid aggressive research intensity goals set by foreign governments. For example, Germany's new coalition government has pledged to boost the country's R&D spending from 2.9 percent to 3.5 percent of GDP by 2025, making Germany a world leader in research spending, behind only South Korea and Israel.[16] The UK's latest economic growth strategy aims to increase UK research intensity by nearly 50 percent over 10 years.[17]

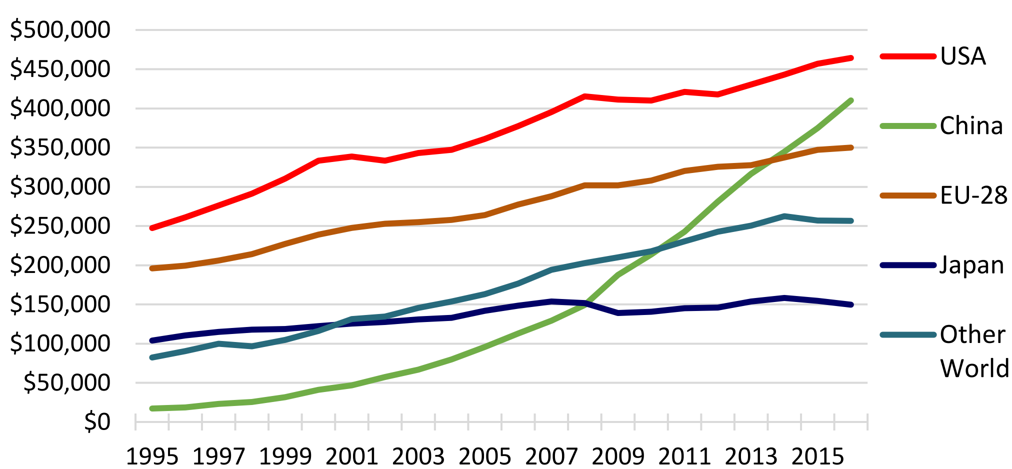
Turning next to basic research specifically – as opposed to total R&D – spending among OECD member

AVERAGE ANNUAL R&D GROWTH IN SELECT ECONOMIES, 2000-2016
Constant dollars

United States	2.1%
China	15.6%
Japan	1.3%
Germany	2.5%
France	1.6%
South Korea	8.3%
U.K.	2.0%
Russia	4.4%
Taiwan	6.8%
Italy	1.6%
Canada	1.0%
Singapore	7.2%

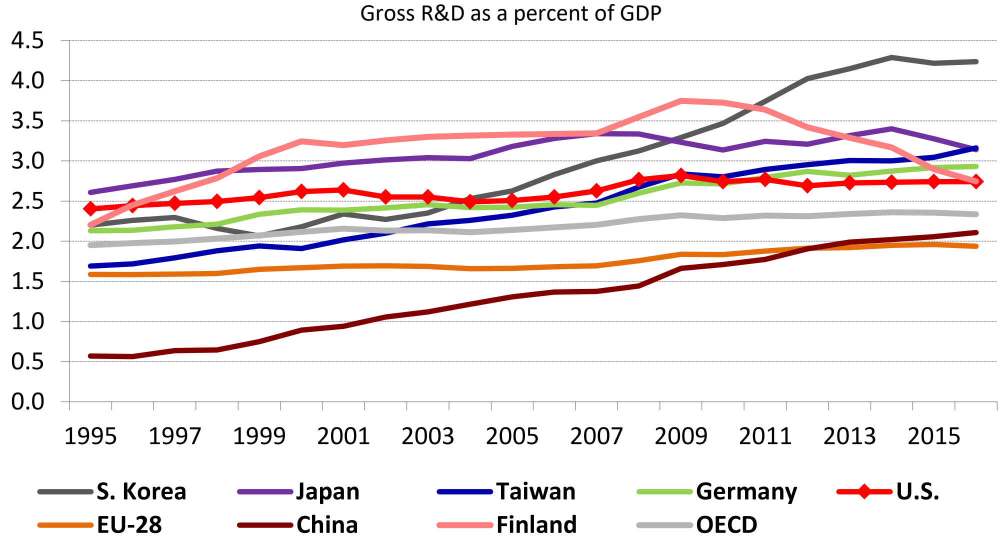
Estimates based on OECD Science and Technology Indicators

Figure 16: World R&D by Country / Region
(millions of constant 2010 dollars adjusted for purchasing power parity)



Source: OECD Science Indicators © 2018 AAAS

Figure 17: International R&D Intensity
Gross R&D as a percent of GDP

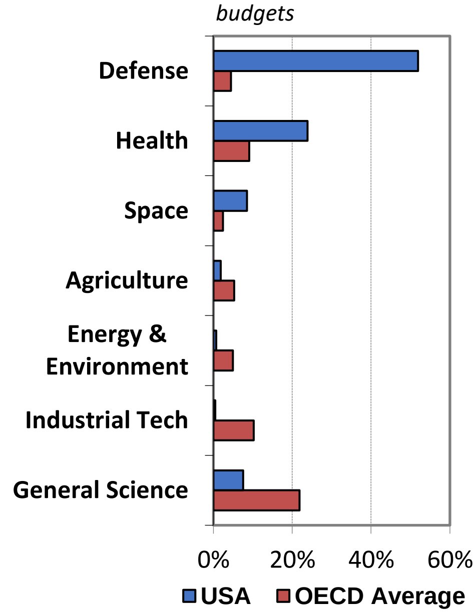


Source: OECD Science & Technology Indicators. © 2018 AAAS

countries has quadrupled since 1985. The U.S. barely cracks the top ten in basic research as a share of GDP, though total American basic research spending remains largest in the world by far. The U.S. and other advanced nations have historically placed a high emphasis on basic research as a key to competitiveness, and some emerging competitors have accordingly assigned a high priority to basic research. For example, South Korea recently announced plans to double its basic research budget by 2022.[18] But this is not the case everywhere. For instance, in spite of its recent rise, China has tended to invest relatively less in basic research and more on applied research and development. In fact, basic research accounted for only 5 percent of Chinese R&D in 2015, compared to the OECD average of 17.2 percent that year.

Within government research portfolios, US spending on **health R&D** remains the highest among OECD nations in both absolute and relative terms (see Figure 18). Additionally, the U.S. devotes the largest share of R&D funding for **defense** purposes, at roughly 50 percent of the federal portfolio in 2016, whereas the European Union set aside only 4.2 percent. However, the fraction of US government research funding for **agriculture** and **energy and**

Figure 18: R&D by Socio-Economic Objective, 2016
as percentage of government R&D budgets



Note: Excludes General University Funds (GUF). Source: OECD Research and Development Statistics database. © 2018 AAAS

environment is nearly the lowest among all OECD countries. The U.S. also assigns just a tiny fraction of its R&D budget for **industrial technology**, including R&D for innovative manufacturing processes. The **general science** function – core basic research that cannot be attributed to a specific objective – ranks surprisingly low in the U.S. compared to most OECD countries. On average, one-third of R&D in OECD countries is for multi-purpose **general university funds** (GUF), government block grants used at the discretion of higher education institutions; the U.S. does not employ a GUF mechanism.

Lastly, it's important to note that the percentage of total R&D funded by government has stagnated and declined globally over the last decade, following the financial crisis. Government funding of R&D within the entire OECD area fell from 31 percent to 27 percent between 2009 and 2016, amid fiscal austerity policies in Europe and budget sequestration in the U.S. This funding slump comes as governments within the advanced OECD economies seek to steer public research towards ambitious "mission-oriented" goals such as healthy aging, clean energy and food security. With public research funding under budgetary pressure in recent years across the OECD, some governments have also started to innovate and experiment with new competitive research funding mechanisms such as lotteries, along with novel peer review processes.[19]

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[1] Joseph E. Stiglitz, "Leaders and Followers: Perspectives on the Nordic Model and the Economics of Innovation," NBER Working Paper 20493, September 2014.

[2] Roli Varma, "Changing Research Cultures in U.S. Industry," *Science, Technology, & Human Values*, Vol. 25 No. 4, Autumn 2000.

[3] National Research Council *Furthering America's Research Enterprise*. R.F. Celeste, A. Griswold, and M.L. Straf (Eds.), National Academies Press, 2014.

[4] Government Accountability Office report GAO-12-470T: "Advanced Research Projects Agency-Energy Could Improve Its Collection of Information from Applications," https://www.gao.gov/products/GAO-12-407T

[5] See Russell J. Funk and Jason Owen-Smith, "A Dynamic Network Measure of Technological Change," *Management Science,* Vol. 63 no. 3, March 2017; Rafael A. Corredoira, Brent D. Goldfarb, and Yuan Shi, "Federal Funding and the Rate and Direction of Inventive Activity," *Research Policy,* Vol. 47, No. 9, November 2018.

[6] See Wesley M. Cohen, Richard R. Nelson, and John P. Walsh, "Links and Impacts: The Influence of Public Research on Industrial R&D." *Management Science,* Vol 48, no. 1, January 2002.

[7] See CBO's most recent Long-Term Budget Outlook: https://www.cbo.gov/publication/53919

[8] See "The Federal Government is Tweaking What Counts as R&D: Q&A," https://www.aaas.org/news/federal-government-tweaking-what-counts-rd-qa

[9] The America COMPETES Acts of 2007 and 2010 sought to double the budgets of NSF, NIST, and DOE's Office of Science. See CRS overview: https://www.everycrsreport.com/files/20150127_R43880_305a7629117b0bd580e48a2b5c6f36a6c5442db8.pdf

[10] See AAAS FY 2018 omnibus summary: https://www.aaas.org/news/omnibus-would-provide-largest-research-increase-nearly-decade

[11] Available at https://www.whitehouse.gov/omb/information-for-agencies/circulars/

[12] For instance, see Venkatesh Narayanamurti, Tolu Odumosu, and Lee Vinsel, "RIP: The Basic/Applied Research Dichotomy," *Issues in Science and Technology*, Winter 2013; Ben Shneiderman, "Toward an Ecological Model of Research and Development," *The Atlantic*, April 23, 2013, http://www.theatlantic.com/technology/archive/2013/04/toward-anecological-model-of-research-and-development/275187/.

[13] http://www.nsf.gov/statistics/natlpatterns/

[14] OECD *Main Science and Technology Indicators*, 2018, http://www.oecd.org/sti/msti.htm

[15] National Science Board, 2018, *The Rise of China in Science and Engineering*, https://nsf.gov/nsb/sei/one-pagers/China-2018.pdf

[16] See coverage on Germany's R&D spending goals: http://science.sciencemag.org/content/359/6380/1081.full

[17] See UK Industrial Strategy: https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future

[18] See announcement from South Korean government: https://en.yna.co.kr/view/AEN20180228009700320

[19] A recent OECD report examined competitive research funding schemes in various countries: https://www.oecd-ilibrary.org/docserver/2ae8c0dc-en.pdf?expires=1545158586&id=id&accname=guest&checksum=084D7C2297467AADE97F4CE84277EB30