Background Paper on the Definition, Value, and Funding of Basic Research in the United States

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Prepared for the CEOs and Leaders for Science Retreat

OVERVIEW

Jobs in America depend on a strong economy, and America's economy is increasingly founded on science and technology. America's technological leadership relies on basic research. But in recent years, the scientific community has inadequately conveyed the importance of science in general and basic research in particular. The fact that basic research is often not focused on a specific result is its strength, not its weakness. From the Internet, the Global Positioning System (GPS) and military stealth technology to the mechanisms behind gene editing and mobile phone technology, the unanticipated byproducts of basic research have enhanced our prosperity, security and well-being as a nation and a part of the global community.

> Basic research "has led to breakthroughs in national defense, communication networks, improved agricultural yields, and has increased our standard of living. Research conducted in one area can be applied elsewhere in unexpected ways. ... These investments do not have an obvious commercial goal, nor a particular process or product in mind at the time of investigation."
>
> — John Watson, Chief Executive Officer, Chevron

"Basic research," writes Rebecca Blank, chancellor of the University of Wisconsin-Madison, "is not focused on a specific applied problem but is designed to expand the boundaries of knowledge in a particular field. …Much of this work has no immediate or obvious application… The majority of basic research is conducted at universities and is what economists call a public good, that is, it provides broad benefits that no one business or individual can easily capture. Public goods are typically underprovided in the marketplace." The federal government is by far the primary funder of basic research, providing 47 percent of funds in 2013. In that same year business was the source of 26 percent of the funds for basic research, while universities and colleges provided nearly 12 percent. Basic research accounted for $80.5 billion, or 18 percent, of the $456.1 billion in research and development (R&D) performed in the U.S. in 2013. Applied research accounted for 20 percent and development, 62 percent.

By underfunding basic research, the private and public sectors risk foregoing equivalent game-changing innovation. Although R&D growth exceeded U.S. Gross Domestic Product (GDP) growth in 2013 (the last year of complete National Science Foundation data), it fell behind the GDP over the five-year period 2008-2013. Over that time, R&D expenditures grew 0.8 percent, compared with 1.2 percent GDP growth (inflation-adjusted). Over the earlier periods 1993-2003 and 2003-2008, the rate of R&D growth in the United States surpassed growth in the GDP. (See Table 4-2, Science and Engineering Indicators 2016)

And yet basic research has produced benefits across government, business, and public life.

Basic research – definition and distinctions

Basic research: systematic study to gain knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications toward processes or products in mind; **Applied research**: systematic study to gain knowledge or understanding necessary for determining the means by which a recognized and specific need may be met; and **Development**: systematic use of the knowledge and understanding gained from research for the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes. (Source: NSF.gov)

The distinctions among types of research are not iron-clad, and the way data are classified within them has changed over time. While the Department of Defense, for example, draws clear distinctions between basic and applied research, in a broader sense research that is "exploratory," and therefore basic, occurs at various stages of development.

"Applied science is purposeful and biased toward direct and tangible benefits," said Amgen chairman and CEO Robert Bradway. "Basic research is motivated by rigorous understanding, and therefore, consistently realizes unexpected and unbiased discoveries. It is grist for the mill of innovation."

Value

Basic research has yielded scientific discoveries that have altered our view of the universe, led to the technological conveniences of daily life, and created the little-seen systems and methods that underlie complex transactions embedded in our society. Federally funded basic research made the iPod and iPhone possible. Such work on large-item exchanges, as developed by Shapely & Scarf with support from the NSF, paved the way for the national medical residency match system, for matching students with schools in public-school choice programs in Boston and New York, and for paired kidney exchange programs (Cook, 2015).

Yet the byproducts of basic research can be difficult if not impossible to foresee. Thirty years may elapse between initial discoveries and practical applications. Such was the case with work in the 1940s by Columbia University physicist I.I. Rabi on energy transitions between hyperfine states of atoms. That work paved the way for atomic clocks and, in the '70s, for magnetic resonance imaging (MRI) and a space-based positioning system that became the foundation for the Global Positioning Systems (GPS). Similarly, in the 1950s Defense Department funding supported initial experiments on so-called metamaterials, which became the basis for stealth technology for aircraft, an application that probably occurred 30 years after that initial work.

Other fruits of basic research include high-frequency electronics, funded initially by the Navy and Air Force, and the Kalman filter, a mathematical technique used to estimate the state of an uncertain system, which is employed in image processing, weather forecasting, and navigation.

Due to its unique nature, basic research that can be applied to national defense usually has to be developed with government funds. Sometimes, research efforts that are started for defense reasons, such as the Internet or GPS, are ultimately of significant value to the economy and draw private investment funds to develop them commercially. Another such technology, a non-invasive fluid characterization technique, was originally developed for defense purposes at Los Alamos National Lab to assess the contents of chemical weapon stockpiles without having to open the munitions. That technology is being used by a partnership of Los Alamos, Chevron and GEO to develop the Safire flow meter, which provides real-time estimates of the amount of oil and water flowing from wells without having to first divert it into a holding tank for measurement.

The Aerospace Corporation, which operates a federally funded research and development center (FFRDC) for the Department of Defense, conducts exploratory research in a number of areas. Among them are nano-satellites, miniaturized spacecraft that can perform high-capability missions at a reduced cost; space environment research, measuring and characterizing the dynamic radiation environment of near-earth space and its effect on materials and electronics; laser communications; and exploiting the unique properties of graphene for space applications, including electronic and photonic devices, solar cells and energy storage devices.

Research by NASA has led to a significant number of top discoveries, ranging from the inspirational (the Pluto fly-by) to essential for a modern society (studies on global change). Weather satellites deployed by the National Oceanic and Atmospheric Administration are made by NASA, and are used to understand the effects of space weather on power grids, GPS and technological systems such as computers and cellphones, and monitor potentially hazardous near-earth objects that could be destructive on a massive scale. Technology developments by NASA discoveries have resulted in spin-offs, with patents and licensing; internal use; direct technology research in aerospace and other applied markets; and partnering with a variety of industries.

In the life sciences, applied technologies have been built upon basic research and discoveries. After basic scientists make fundamental discoveries (such as the mechanisms that break and join DNA), applied scientists convert them into tangible economic and social benefits, such as medicines made with recombinant proteins and tools for gene analysis. Those can be refined even further, as was the case with the CRISPR-Cas9 mechanism, which is revolutionizing the field of genetic engineering, but which emanated from basic science studies of archaebacteria.

Economist Mariana Mazzucato observes that “every technology that makes the iPhone smart and not stupid owes its funding to both basic and applied research funded by the state” (2015). These include contributions such as the microprocessor (Defense Advanced Research Projects Agency or DARPA), micro hard drive (Department of Energy or DoE, DARPA), the Internet (DARPA), cellular technology (U.S. military), lithium-ion batteries (Department of Energy), global positioning system (Defense Department, Navy), multi-touch screen (DoE, CIA, National Science Foundation (NSF), Defense Department). (For examples of NSF-funded inventions and discoveries: NSF & Congress Toolkit and the NSF’s Nifty 50.)

Additionally, according to the New York Times, an Academy of Radiology Research report found:

> Every $100 million invested in research by the National Institutes of Health, according to the R&D consulting firm Battelle, generates almost six patents. At the National Science Foundation $100 million generates more than 10. At the National Institute of Biomedical Imaging and Bioengineering – which finances radiology – it produces almost 25 patents. And these patents sparked $578.2 million worth of additional R&D further downstream.

Case studies show that government-funded research has contributed to private-sector innovation carrying economic benefits and, in certain cases, quantifiable results. Fay Lomax Cook, the assistant National Science Foundation director for the Social, Behavioral, and Economic Sciences, notes that studies of the application of game theory to auctions paved the way for FCC spectrum auctions, which have brought $120 billion to the U.S. Treasury since 1994.

More broadly, growth in total economic output in the U.S. is driven by three factors – productivity, capital, and labor. Research in the basic sciences of physics, chemistry, and biology drives economic growth through fundamental breakthroughs that affect the size and productivity of the labor force. Advances in the basic sciences have improved our understanding of the behavioral underpinnings of the economic decision-making at the heart of the capital markets and financial services businesses. Basic research-driven changes in technology, such as mobile devices and artificial intelligence, have brought profound changes to the financial services sector.

QUESTION FOR DISCUSSION: While research may hold a wide array of potential policy implications, it is important that policy agendas not attempt to dictate results or commercial outcomes. Such was the case, notes Chevron CEO Watson, when government policy dictated winners in the establishment of the Renewable Fuel Standard. Despite the billions of dollars spent by industry to research future energy needs, breakthroughs have not yielded the quantity of advanced biofuel that was federally mandated.

The overall funding picture

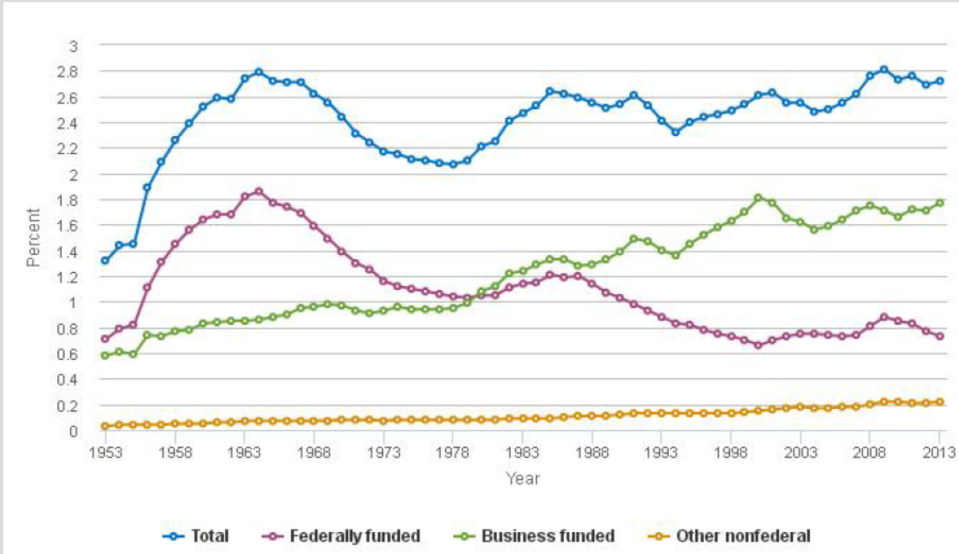
Funders of research and development in the U.S. include the federal government, business, higher education institutions, and other nonprofits such as private foundations. From the early ’50s through the Cold War, the Apollo program and the Vietnam War, the federal government was the dominant funder of R&D. But in 1980, following a decades-long slide in federal funding, the balance shifted and business assumed the larger share.

The gap between business and federal R&D funding has widened. However the vast majority of business funding is dedicated to development—just 7 percent in 2013 was allocated to basic research.

Overall U.S. spending on research and development has continued to grow. The main source of R&D funding is business. After a decline during the recession, business R&D spending has resumed its growth, while federal R&D funding—which spiked after the 2009 Stimulus—has been dropping in constant dollars and relative to the GDP.

Figure 4-3

Ratio of U.S. R&D to gross domestic product, by roles of federal, business, and other nonfederal funding for R&D: 1953–2013



NOTES: Data for 2013 include some estimates and may later be revised. The federally funded data represent the federal government as a funder of R&D by all performers; the business-funded data have a similar function. The Other nonfederal category includes R&D funded by all other sources—mainly universities and colleges, nonfederal government, and other nonprofit organizations. The gross domestic product data used reflect the U.S. Bureau of Economic Analysis's comprehensive revisions of the national income and product accounts of July 2013.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series).

Science and Engineering Indicators 2016

(Source: NSB Science and Engineering Indicators 2016 Report, January 2016)

Research and development and the Gross Domestic Product

In the United States, overall R&D in all economic sectors totaled $456.1 billion in 2013, according to the National Science Board's Science and Engineering Indicators 2016. That's an increase from $435.3 billion in 2012 and $427.8 billion in 2011 (Table 4-1). Those gains follow essentially flat levels, starting with the recession, in 2008-2010, and can be largely attributed to increases in "performance" of R&D by businesses. (For the report, the NSF's National Center for Science and Engineering Statistics measures expenditures on R&D as "performed by" different sectors and then by the source of the funds.) The data come from business, the federal government (including federally funded research and development centers or FFRDCs, such as Brookhaven National Lab), nonfederal government, and higher education.

In 2012-13, the total growth of R&D (3.2 percent) outpaced the GDP (2.2 percent). But over the previous five-year period, 2008-2013, inflation-adjusted growth in U.S. R&D averaged only 0.8 percent annually, falling behind the average GDP growth of 1.2 percent (Table 4-2). That's a reversal of the longer-term trends seen in prior periods when R&D growth exceeded the GDP.

BUSINESS FUNDING

- The business sector funds most U.S. R&D – in 2013, it was the source of nearly two-thirds (65 percent), compared with 27 percent from federal sources (Figure 4-4, Indicators 2016). But, as we noted a moment ago, the majority of the $297 billion spent on R&D by business is dedicated to development ($230 billion or 77 percent) and applied research ($46 billion or 16 percent). Just 7 percent, or $21 billion, was spent on basic research.

- In the last few years, following major cuts in overall R&D during 2008-2010, the business sector substantially increased its spending for R&D, including basic research. Relative to the GDP, business R&D investment has been fairly consistent since the late ’90s, fluctuating within a range of 1.56 and 1.81 percent.

Business as the dominant funder and performer of R&D

Of the $456.1 billion expended in total R&D in the United States in 2013, business provided 65.2 percent of the funding, the federal government provided 26.7 percent, and universities and colleges provided 3.3 percent. (The remainder was nonfederal government and other nonprofit institutions.)

Business has also long been dominant as a performer of R&D, with its annual share ranging from 68 percent to 74 percent of the national total over the 20-year period 1993-2013.

In 2013, 71 percent of R&D was performed by business, 14 percent by higher education, and 11 percent by the federal government (including 7 percent by federal agencies and 4 percent by FFRDCs). Another 4 percent of R&D was performed by other nonprofits and nonfederal governments.

As is the case with overall U.S. R&D, inflation-adjusted growth in business-performed R&D has fallen behind the GDP in the most recent five-year period tracked by the NSF. The increase in business R&D from 2008-2013—a period that includes cutbacks during the recession—averaged 0.6 percent annually, falling behind the 0.8 percent U.S. R&D and the 1.2 percent average GDP growth. In the earlier periods 2003-2008 and 1993-2003, business R&D growth outpaced GDP growth. (InfoBrief, Table 2)

Business and basic R&D

Although business is the primary overall funder for R&D, the federal government is the primary source of money for basic R&D. The federal government accounted for 47 percent of the $80.5 billion spent on basic R&D in 2013, followed by business (26 percent), other nonprofits (12 percent), higher educational institutions (12 percent), and nonfederal government (3 percent), according to NSF data.

As mentioned earlier, of the total $297.3 billion spent by the business sector on R&D in 2013, about $21 billion (7 percent) was spent on basic research. Viewed another way, of the $80.5 billion *performed* in U.S. basic research in 2013, $19.5 billion (24 percent) was performed by the business sector.

The largest performer of basic R&D was higher education. Colleges and universities generated a little more than half of basic research (51 percent), followed by business (24 percent), other nonprofits (12 percent) and the federal government (12 percent). (See Figures 1 through 4 in Appendix I.)

The way that industry regards its role in performing basic research seems to have changed, according to the MIT Committee to Evaluate the Innovation Deficit. "In the past, U.S. industry took a long term view of R&D and did fundamental research, activities associated with such entities as the now-diminished Bell Labs and Xerox Park," the MIT committee wrote in The Future Postponed: Why Declining Investment in Basic Research Threatens a U.S. Innovation Deficit (2015):

> That's still the case in some other countries such as South Korea. Samsung, for example, spent decades to develop the underlying science and manufacturing behind organic light-emitting diodes (OLEDs) before commercializing these into the now familiar, dramatic displays in TVs and many other digital devices. But today, as competitive pressures have increased, basic research has essentially disappeared from U.S. companies, leaving them dependent on federally-funded, university-based basic research to fuel innovation. This shift means that federal support of basic research is even more tightly coupled to national economic competiveness.

Has there been a 2015 surge in business-funded R&D?

Press accounts have described a boost in business-funded R&D in 2015. In the Aug. 24, 2015 New Yorker article "The Short-Termism Myth," James Surowiecki wrote that corporate spending on R&D "is accelerating at its fastest pace in fifty years and is at an all-time high as a percentage of G.D.P." A Bloomberg Business story in June 2015 made similar assertions, using data from the Bureau of Economic Analysis (BEA) in the Commerce Department. But the BEA data on R&D excludes software development, which is a significant part of the total. In 2013, the last full year of NSF data, business-funded R&D was 1.77 percent of GDP, less than the 1.81 percent in 2000. While business funding for R&D has been growing, a complete picture for 2014 and 2015 is not yet available. In any case, as Forbes contributor Steve Denning wrote in "Is Short-Termism a Myth?" (Aug. 20, 2015): "A spike in R&D spending in 2015 would not mean very much, as the numbers have been bouncing around the long term average for years."

FEDERAL FUNDING

Federal spending on R&D is now essentially flat after coming down from its 2010 peak. In recent history the federal R&D budget saw three phases, according to the American Association for the Advancement of Science (AAAS):

- Growth 1997-2003, a period of federal surpluses, with the doubling of the budget for the National Institutes of Health amid public health concerns and post-9/11 growth in defense spending;
- Flat 2003-2010, with continuing elevated defense spending and slowing nondefense funding, a period which ended with a final-year spike in nondefense funding because of ARRA (the American Recovery and Reinvestment Act, also known as "the Stimulus");
- Post-2010, a decline and leveling off due to diminished defense R&D and more recently, government spending caps (also known as sequestration or "the Sequester"). During this period the federal R&D budget declined 15.4 percent.

In addition:

- Relative to the GDP, federal spending on R&D has declined over the last four decades. From 1.23 percent of GDP in 1976, federal R&D spending has fallen below 1 percent since 2011, according to AAAS data. Although most major R&D agencies have recovered to or near their pre-sequestration levels as of early 2016, thanks to favorable outcomes on recent omnibus spending bills, there are issues with the proposed fiscal year 2017 budget that could affect that.

- The Obama Administration's final budget, for fiscal year 2017, proposes two types of R&D funding – a base budget that observes the spending cap agreed on with Congress, and proposals for new mandatory spending, which would require new authorizing legislation. In the President's proposed 2017 budget, base federal funding on R&D would drop to 0.75 percent of GDP, the lowest since the Space Race. If the mandatory R&D spending is included, federal R&D would hold steady at 0.78 percent of GDP, according to the AAAS. In 2017, overall funding for research alone (basic and applied) will be at the bottom of its historic range since 1976, at 0.35 percent of GDP (in the base budget) or 0.37 percent if mandatory spending is included, which would equal 2016. (Note: AAAS and NSF data reflect different information and sources; NSF data are based on surveys of performers, which report expenditures and sources; AAAS gathers information from federal agencies' budgets and appropriations.)

- Federal R&D as a percent of GDP is likely to continue its decline, in part because of the growth of entitlement programs. However, the larger proportional drop in R&D has been in development, which since 1976 has declined from 0.74 percent of GDP to 0.40 percent, attributable in part to the end of Cold War defense research and the end of the Apollo program.

- Federal funding on R&D has also declined as a proportion of the federal budget, from more than 10 percent in the late '60s to less than 4 percent today.

In Restoring the Foundation : The Vital Role of Research in Preserving the American Dream (2014), an American Academy of Arts and Sciences committee calculates what it calls a "basic research investment shortfall" by the federal government if basic research funding remains flat. The Academy looks at 1975-1992 as a period of "competitive, sustainable growth" in the federal basic research budget (4.4 percent average annual real growth). Using that as a trend, the Academy's Committee on New Models for U.S. Science & Technology Policy recommends a return to a more competitive growth rate for the federal government to close what it sees as a cumulative $639 billion "basic research investment shortfall."

GLOBAL COMPARISONS

- In global competitiveness, the U.S. has fallen to 10th place in R&D intensity, a measure of R&D spending as a percentage of GDP, according to the OECD. China, second to the U.S. in R&D spending, is on pace to surpass the U.S. in spending and in R&D intensity within a decade.

- China accounts for 20 percent of global R&D, compared with 27 percent for the United States, according to the NSF's Indicators 2016 report. But from 2003-2013, China increased its R&D investments at an average 19.5 percent a year, far exceeding the U.S. average of 4.5 percent.

- Leading scientific achievements in 2014—including development of the world's fastest supercomputer, the first landing on a comet—came not from the United States but, in these cases, Europe and China.

Global R&D

The United States spends more on R&D—also known as GERD, gross domestic expenditure on R&D—than any other country. In 2013, according to the Organisation for Economic Co-operation and Development (OECD), the U.S. spent $456 billion on R&D, followed by China ($336B), Japan ($160B), Germany ($101B), and South Korea ($69B). The list of top-spending nations in R&D is rounded out by France ($55B), Russia ($41B), and the U.K. ($40B). (No. 9 is India, which is not tracked by the OECD.)

In the critical measure of R&D intensity, however, U.S. spending lags other nations and is losing ground. R&D intensity reflects R&D expenditures as a percentage of Gross Domestic Product. Since 1992, when the U.S. ranked second only to Japan in research intensity, the United States has fallen to 10th place. (See OECD data, and Restoring the Foundation. The NSF has the U.S. even slightly lower, at 11th.) By this measure, U.S. gross R&D spending in 2013 was 2.73 percent, below that of Germany (2.85 percent) and just above Slovenia (2.59 percent). Leaders in this measure are Israel (4.21 percent), Korea (4.15 percent) and Japan (3.47 percent).

(For graphics, see Figures 5 through 8 in Appendix I.)

The implications of this slippage in U.S. rank are troubling. While China's national investment on R&D ranked second to the United States and was more than $100B annually behind the U.S. in 2013, its R&D intensity has been growing at an average of 8 percent a year in pursuit of China's annual goal of R&D spending of 3 percent of GDP. At that pace, China will surpass the U.S. in R&D intensity in eight years (Restoring the Foundation) and "is expected to exceed the United States in dollars spent in the near future," writes Rebecca M. Blank, chancellor of the University of Wisconsin-Madison (The Annals, The American Academy of Political and Social Science, January 2016). Blank continued: "The long-term effect of these differences in research investment is that the new breakthroughs of tomorrow are more likely to emerge in countries other than the United States – and the industry and job and economic growth that come with these breakthroughs will not be located here either."

Indeed, the MIT report The Future Postponed examines 15 areas of research in which U.S. leadership is threatened, underfunded or lacking, including Alzheimer's Disease, cybersecurity, space exploration, fusion energy, and infectious disease. The report cites four major scientific achievements of the last year—the discovery of the Higgs boson; development of the world's fastest supercomputer; new research in plant biology; and the first spacecraft landing on a comet—and points out that none of them resulted from efforts led by the U.S. (See MIT report, also Hiltzik, "Reduced public funding for basic research leaves U.S. in the scientific dust" (The Los Angeles Times, April 28, 2015).)

Global growth in business-funded R&D – especially in China

An analysis by PricewaterhouseCoopers published in Strategy & Business (October 27, 2015) tracks the Global Innovation 1000, the 1,000 public corporations worldwide that spent the most on R&D in products and services for their markets. Innovation's New World Order reported that worldwide R&D spending by those companies rose 5.1 percent to $680 billion in 2015, the strongest year-over-year increase in three years. Companies with headquarters in the U.S., Europe and Japan accounted for 86 percent of that. Revenues for those 1,000 firms dipped slightly—attributed to collapsing oil prices—which the report said had the effect of slightly elevating the "research intensity," or R&D ("innovation spending") as a percentage of revenue, to 3.7 percent in 2015 from 3.5 percent in 2014.

According to this analysis, spending by region in 2014-2015 was led by growth in China. Companies headquartered in China showed a 31.6 percent growth in R&D, compared with 7.1 percent in North America, 4 percent in Europe, and -6.3 percent in Japan. (Other parts of the world collectively showed 9.5 percent growth.)

The Future

At a time when government investment in research is lagging and the private sector is only partially taking up the slack, some essential needs – in defense, biotechnology, health care, energy, space science and other sectors across the economy—can be met only by intensive investment from both the federal and private sectors. The Defense Department's Office of the Assistant Secretary of Defense, Research and Engineering has developed a list of "emerging areas," essentially a strategic plan for investment, which includes:

- Synthetic biology, modifying living cells to produce novel substances such as bio-fuels, bio-sensors, improved vaccines, and high-strength materials;
- Quantum information science, a way to perform complex numerical calculations to develop ultra-secure communications;
- Cognitive neuroscience, to provide a deeper understanding of human learning and decision-making, improve performance under stress and reduce the effects of war trauma;
- Understanding human and social behavior, to enhance strategic and tactical decision-making, improve immersive training and mission rehearsal, and facilitate cross-cultural coalition building;
- Novel engineered materials, including superconductors and metamaterials;
- Nanoscience, making possible new classes of electronics and sensors, chemical catalysts and high strength-materials.

The biopharmaceutical sector is depending on basic science to fill gaps in knowledge that will contribute to development of the next generation of medicines – for instance, understanding the mechanistic basis of thoughts, memories and emotions, which is a key to treating neuropsychiatric disorders; and understanding the predictability of molecular interactions, including those between a drug and its target. The financial sector looks to basic science for studies on growing old, life span, and individual productivity, as declining population growth and longer lives will significantly affect the financial services industry. Studies of brain chemistry have given rise to the emerging fields such as neuro-finance, and understanding which parts of the brain are associated with rational and suboptimal choices.

The Challenge

> "Investments in R&D often have 'spillover' effects; that is, a part of the returns to the investment accrue to parties other than the investor. As a result, investments that are worth making for society at large might not be profitable for any one firm, leaving aggregate R&D investment below the socially optimal level… These positive spillovers can be particularly large for basic scientific research. Discoveries made through basic research are often of great social value because of their broad applicability, but are of little value to any individual private firm, which would likely have few, if any, profitable applications for them."
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> — 2014 Economic Report of the President

Conclusion

The diminishing level of federal investment in R&D, said Joseph Quinlan, chief market strategist at U.S. Trust, Bank of America Private Wealth Management, is the answer to the often-asked question "So what keeps you awake at night?" In a May report, according to Bloomberg Business, Quinlan wrote that "Federally funded research pays powerful innovation dividends, which, incidentally, accrue to savvy investors." Citing the federal role in developing technology for fracking and for cancer drugs, he added: "America is short-changing its future by forgoing outlays in basic research and development."

***A note on sources and data*:**

There are many versions of the data and charts cited here. Three primary sources are cited. Published data from the **National Science Foundation** (National Center for Science and Engineering Studies) is based on surveys of research performers in accordance with international standards in the Frascati Manual. The most current data are through 2013. The **American Association for the Advancement of Science** (AAAS) uses federal appropriations and budget data for federal outlays, including analysis through the FY 2017 proposed budget. The **Organization for Economic Co-operation and Development** (OECD), which analyzes data from 34 member democracies with market economies and seven non-members, including China and Russia, gathers data which currently ends in 2013 (its U.S. data comes from the NSF). The OECD uses purchasing power parity (PPP), an international convention for converting foreign currency into U.S. dollars. In addition, annual figures may be restated and retroactively adjusted.

Selected sources and further reading

Science and Engineering Indicators 2016 (Full report: National Science Board, January 19, 2016); Digest and Chapter 4 (Research and Development: National Trends and International Comparisons)

Guide to the President's Budget: Research and Development FY 2017 (AAAS, March 22, 2016)

Federal R&D Budget Trends: A Short Summary (AAAS, Jan. 15, 2015)

Historical Trends in Federal R&D (tables and charts, AAAS)

Historical Trends in Federal R&D (PDF, AAAS)

U.S. R&D Increased in 2013, Well Ahead of the Pace of Gross Domestic Product (NSF, Sept. 8, 2015)

Main Science and Technology Indicators (OECD global data, July 2015)

Restoring the Foundation: The Vital Role of Research in Preserving the American Dream (American Academy of Arts & Sciences, Sept. 16, 2014)

The Future Postponed: Why Declining Investment in Basic Research Threatens a U.S. Innovation Deficit (MIT, April 2015)

Patents as Proxies Revisited: NIH Innovation 2000 to 2013 (Battelle Technology Partnership Practice, prepared for The Academy of Radiation Research, March 2015)

2014 Global R&D Funding Forecast (Battelle, December 2013)

Innovation's New World Order: The Global Innovation 1000. (PricewaterhouseCoopers/Strategy & Business, Winter 2015)

Blank, Rebecca. "What Drives American Competitiveness?" (The Annals, American Academy of Political and Social Science, January 2016.)

Pielke Jr., Roger. "Basic research as a political symbol." (Minerva 50.3 (2012): 339-361.)

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Appendix I

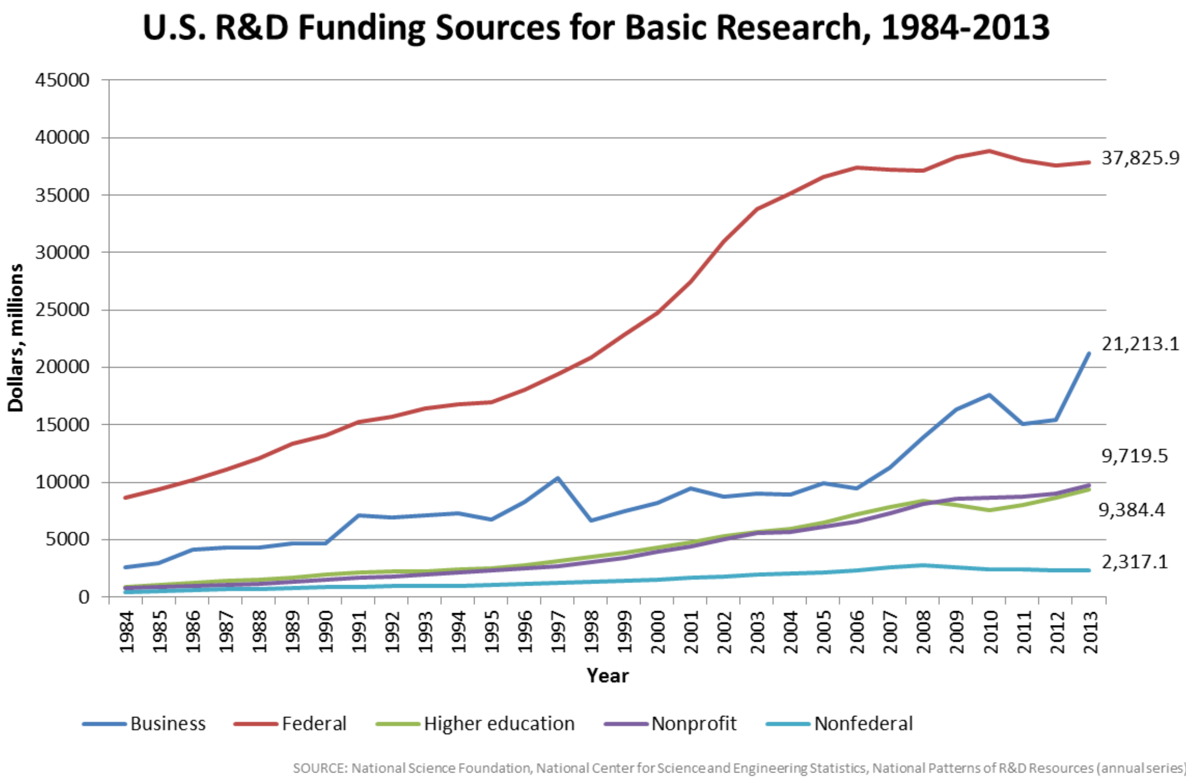

Figure 1. Source: The National Science Foundation's National Center for Science and Engineering Statistics.

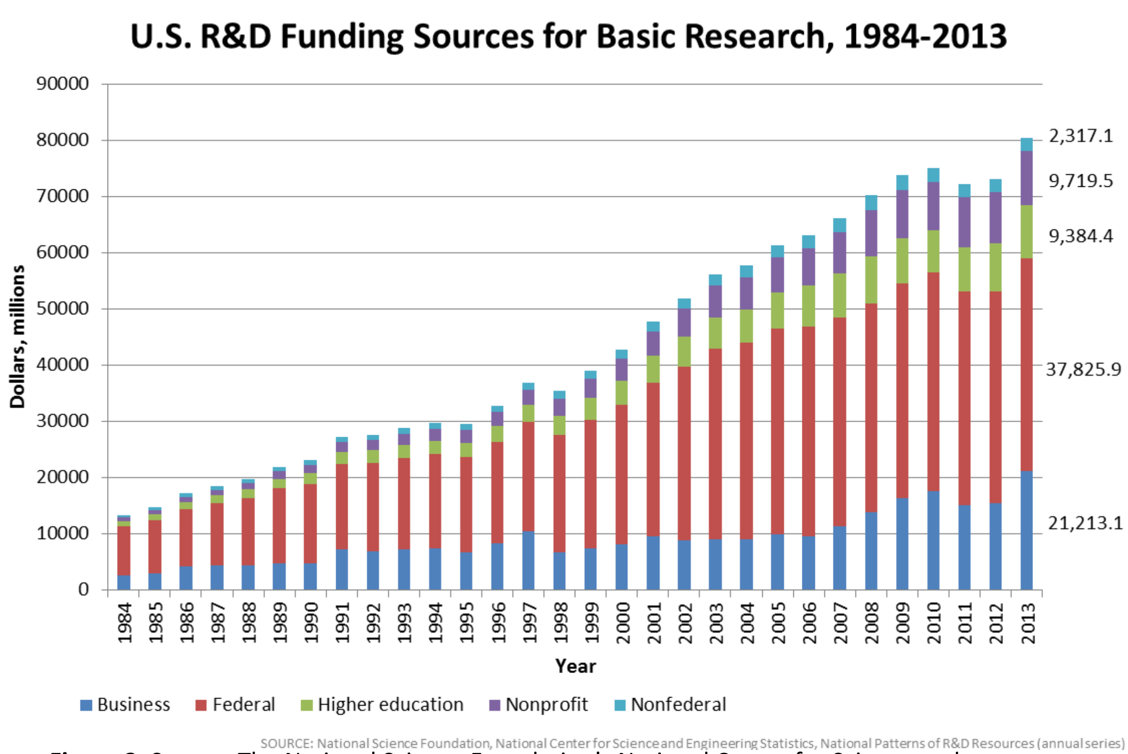

Figure 2. Source: The National Science Foundation's National Center for Science and Engineering Statistics.

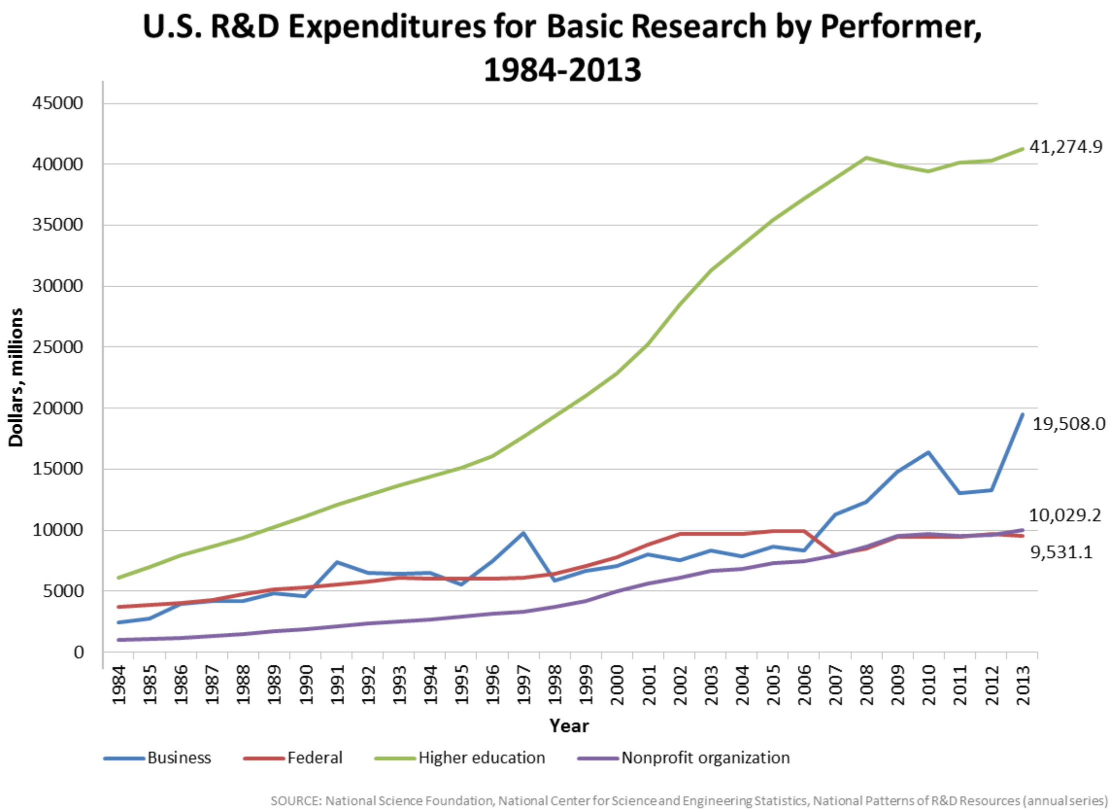

Figure 3. Source: The National Science Foundation's National Center for Science and Engineering Statistics.

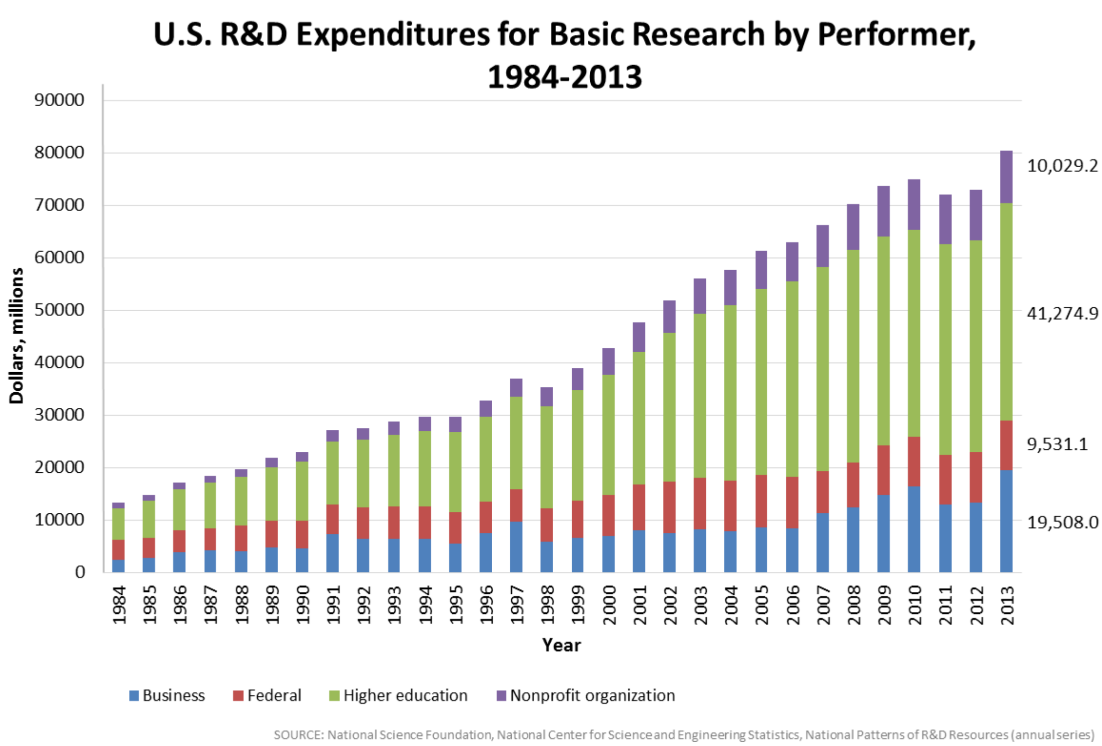

Figure 4. Source: The National Science Foundation's National Center for Science and Engineering Statistics.

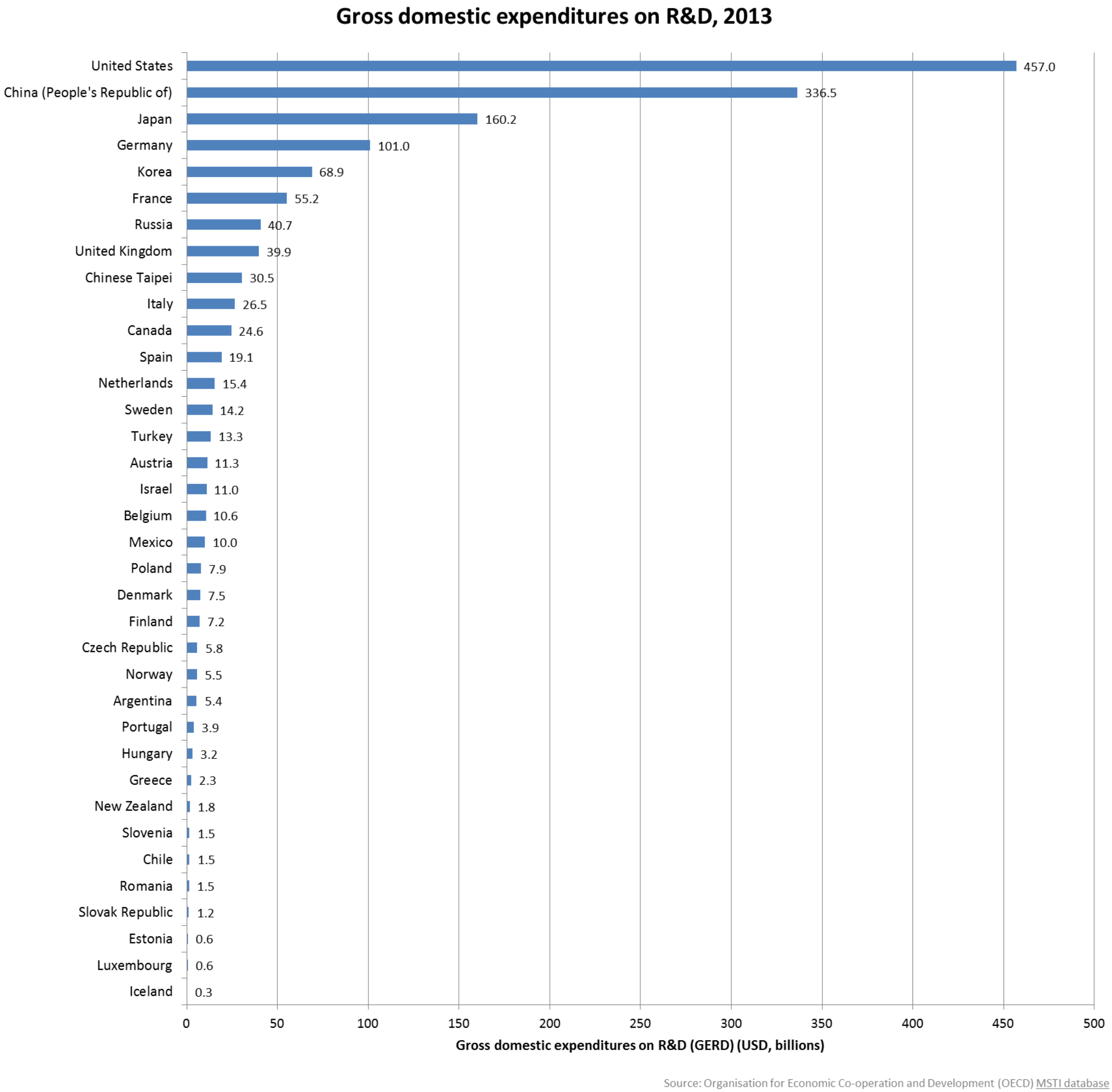

Figure 5. Gross domestic expenditures on R&D in 2013. Source: OECD MSTI database.

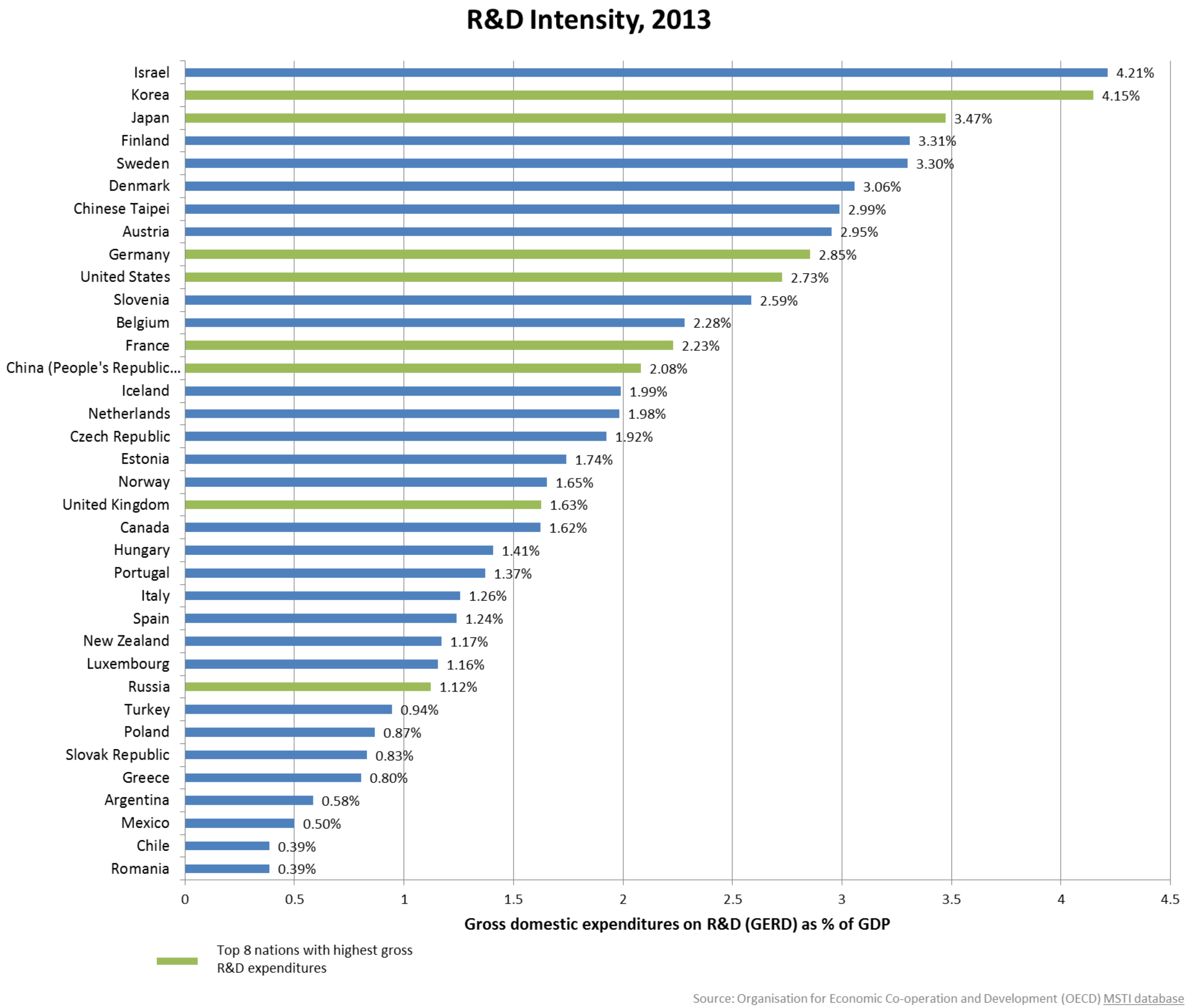

Figure 6. R&D intensity or gross domestic expenditures on R&D as a percentage of GDP. Source: OECD MSTI database.

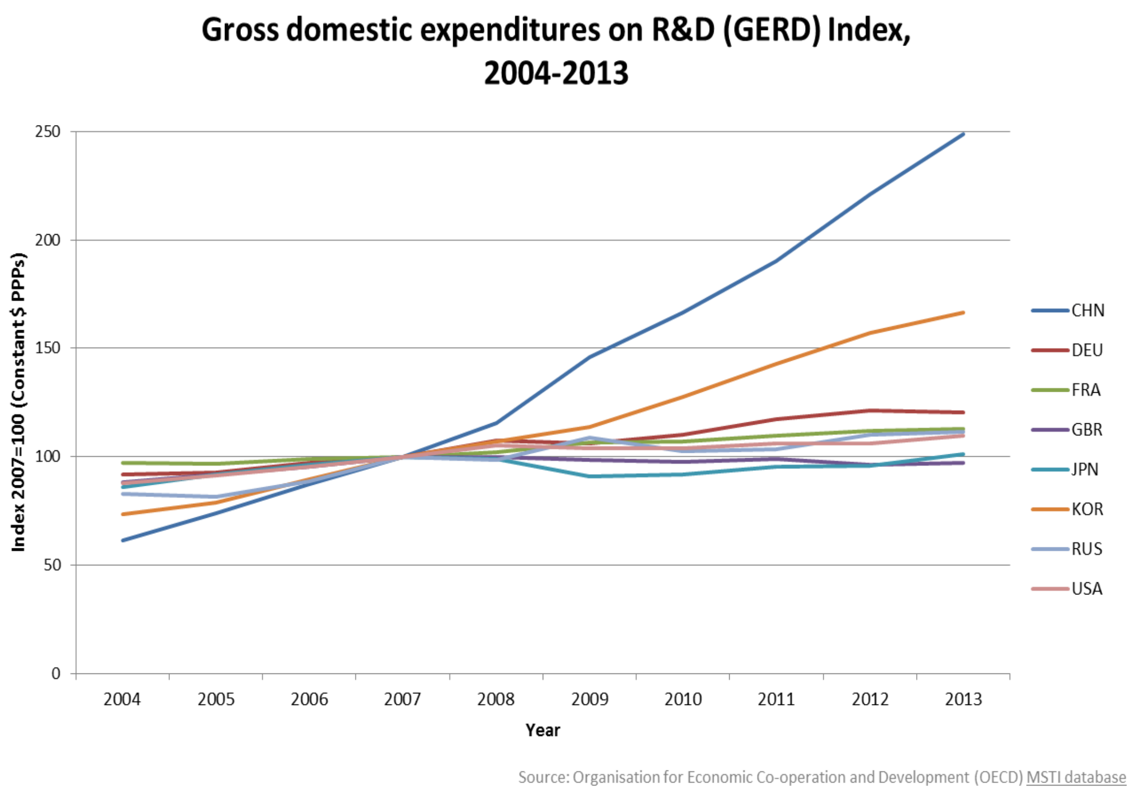

Figure 7. Gross domestic expenditures on R&D (GERD) Index 2004-2013 for the leading countries tracked by the OECD. Source: OECD MSTI database.

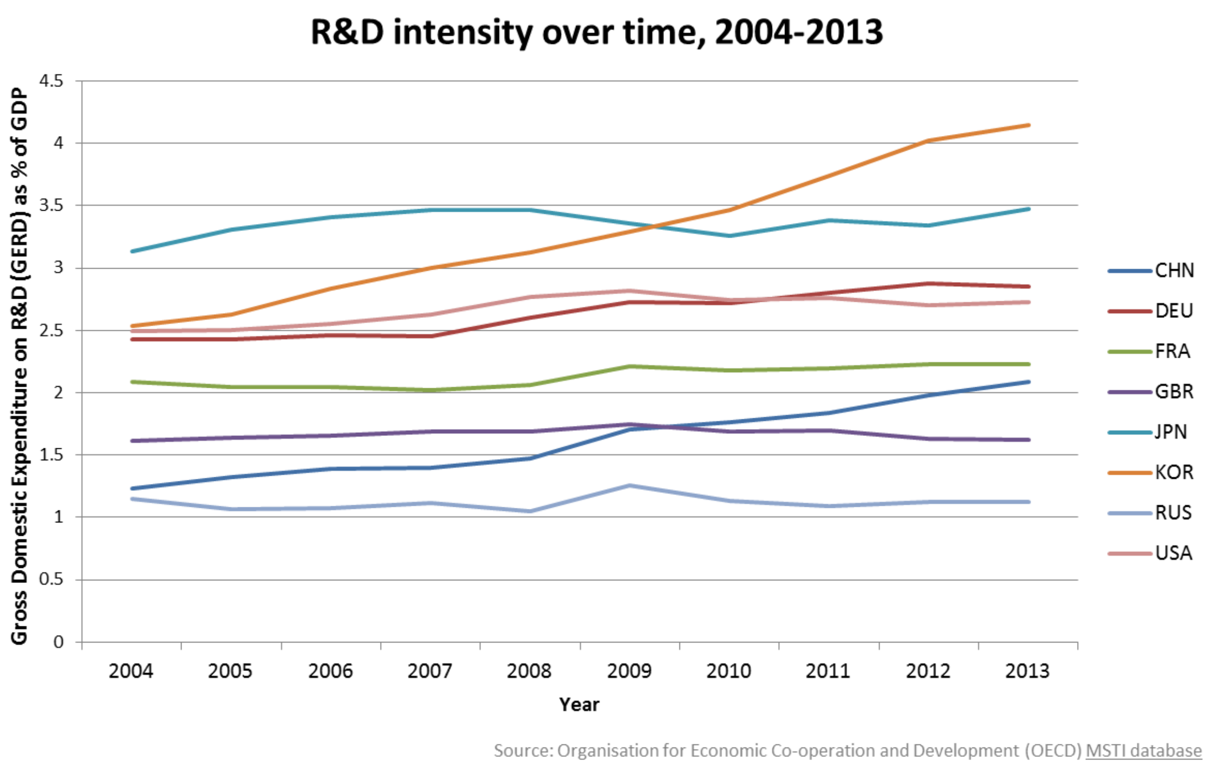

Figure 8. R&D intensity (gross domestic expenditure on R&D as a percent of a nation's GDP) for the leading countries in R&D expenditures. Source: OECD MSTI database.

Appendix II

Responding to misuses of evidence in the case against government-funded basic research

In his essay "The Myth of Basic Science" (The Wall Street Journal, Oct. 24, 2015), Matt Ridley, a zoologist and Conservative member of the British House of Lords, contends that technological evolution has a momentum of its own and that many renowned developments—e.g., Thomas Edison and the light bulb—are the fruits of discovery by many inventors. He argues against "the article of faith that science would not get funded if government did not do it, and economic growth would not happen if science did not get funded by the taxpayer."

He cites a 2003 OECD report as having found that "publicly funded research had no economic impact whatsoever. None." But that is an overstatement of what the OECD found. While the OECD analysis said it "could find no clear-cut relationship between public R&D activities and growth, at least in the short term," it added: "The significance of this latter result should not however be overplayed as there are important interactions between public and private R&D activities as well as difficult-to-measure benefits from public R&D (e.g. defence, energy, health and university research) from the generation of basic knowledge that provides technology spillovers in the long run."

Ridley also references the 2001 study "International R&D Spillovers and OECD Economic Growth" by economist Walter Park of American University, as saying that "public funding of research almost certainly crowds out private funding." Examining growth, Park found that "the direct effect of public growth is weakly negative, as might be the case if public research spending has crowding-out effects which adversely affect private output growth." But Park also noted that "this is not to suggest that public research cannot influence productivity growth, for it may do so indirectly by stimulating private research investment."

In his book "The Evolution of Everything," Ridley arrives at a more generous conclusion about the role government science funding than in his essay. Discussing Park's work, Ridley asserts: "… [I]f the government spends money on the wrong kind of science, it tends to stop people working on the right kind of science. But, given that the government takes more than one-third of a nation's GDP in most countries and spends it on something, it would be a pity if none of that money found its way to science, which is after all one of the great triumphs of our culture. … Innovation, then, is an emergent phenomenon. The policies that have been tried to get it going – patents, prizes, government funding of science – may sometimes help, but are generally splendidly unpredictable."

There are a variety of flaws in Ridley's argument, many of them cited above. In addition, Robert D. Atkinson, president of the Information Technology and Innovation Foundation, writes in "The assault on federally supported science" in the Christian Science Monitor that Ridley misreads the OECD report as well as one from an economist with the Bureau of Labor Statistics. Atkinson said the BLS report did not show that the return on investment from publicly financed R&D was near zero, but rather measured the impact of R&D on productivity in government agencies (which is low). Atkinson says Ridley also ignores "the many cases where basic science laid the groundwork for mechanical inventions."