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BASIC RESEARCH AND THE INNOVATION FRONTIER

Decentralizing Federal Support and Stimulating Market Solutions

Mark P. Mills
Senior Fellow, Manhattan Institute

CEPE
CENTER FOR ENERGY POLICY AND THE ENVIRONMENT
AT THE MANHATTAN INSTITUTE

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Executive Summary

In the modern era, basic scientific research—a "public good," often involving the pursuit of knowledge for its own sake—has been foundational to innovation and thus, to economic growth and social progress. Fostering yet more open-ended research will give rise to the fundamental breakthroughs needed to revolutionize everything from health care and security to energy and the environment.

But overall, U.S. leadership in basic research is slipping. Funding support, in both absolute and relative terms, has been slowing for decades; in the last few years, this decline has accelerated. The erosion of support for American scientists on the innovation frontier will create a damaging deficit of innovation in the future. And it will only grow worse, with rising congressional pressure to cut "discretionary" spending.

Because the nature of basic research is long-term and indeterminate, it is logical that 90 percent of such funding comes from the federal government. Indeed, barely 5 percent of private R&D spending goes to basic research. Increasingly, too, federal agencies are focused on applied research—which emphasizes near-term problems and projects—competing, in effect, with the private sector, which already spends roughly 400 percent more on applied R&D. This alarming trend represents a de facto conversion of U.S. R&D policy into industrial policy.

Although an array of 29 federal civilian agencies dispense R&D funds, 90 percent of spending decisions are concentrated in just five agencies that are highly susceptible to lobbying and other political pressures. This hyper-concentration has led not only to a decreasing success rate for researchers applying for funds but also to a deeply unproductive bureaucratization of research itself: federally funded researchers now waste nearly half their time performing administrative tasks. Meanwhile, inherently risk-averse federal administrators increasingly focus on funding older, established researchers, leading to a radical decrease in support for young scientists, who constitute a vital part of any intellectually diverse, vibrant, and productive research community.

There is good news: the U.S. still boasts the world's greatest concentration of scientists and leading research universities. What's more, entirely new classes of research tools are emerging: from microscopes that view molecules in real time, to big data analytics that model or emulate reality, to cognitive computing that amplifies scientists' explorations. In addition, private-sector spending on overall R&D—already fourfold greater than federal spending—is rising, although mainly in applied domains. This paper concludes by proposing four high-level policy reforms:

1. Decentralize Federal R&D Spending. Currently, researchers must petition a handful of agencies in Washington, D.C., for funds. Instead, authority for awarding and monitoring the majority of federally funded basic research should be given to the hundreds of extraordinarily capable U.S. research universities and institutions. This would broaden and enliven basic research by leading to more funding for younger researchers, as well as greater variety in the pursuit and administration of the science enterprise.

2. Incentivize More Private Spending on Basic Research. Through tax policies and other means, encourage greater private-sector outlays on basic research in corporate laboratories and (especially) in the nation's universities.

3. De-Bureaucratize Grant Approval and Monitoring. Use modern information tools to radically reduce the crushing nanny-state policing of scientists.

4. Reduce Federal Funding for Industrial-Class Project Development. A boost for federal support for basic research should come by offsetting cuts in spending in industrial-development types of applied research.

Nobel economist Edmund Phelps has pointed out that the very nature of America's culture and capitalist model gives it an inherent advantage in capturing the benefits of scientific advances. Private-sector money and the organizational models and talent in U.S. research universities and institutions are all available. It is time to deploy both toward revitalizing the nation's basic science enterprise.

About the Author

MARK P. MILLS is a senior fellow of the Manhattan Institute and CEO of the Digital Power Group, a tech-centric capital advisory group. He was the cofounder and former chief tech strategist for Digital Power Capital, a boutique venture fund. Mills cofounded and served as chairman and CTO of ICx Technologies, helping take it public in a 2007 IPO. He is a member of the advisory council of the McCormick School of Engineering and Applied Science at Northwestern University and is a member of the Advisory Board of Notre Dame's Reilly Center for Science, Technology, and Values.

Mills writes the "Energy Intelligence" column for *Forbes* and is coauthor of the book *The Bottomless Well: The Twilight of Fuel, the Virtue of Waste, and Why We Will Never Run Out of Energy* (Basic Books, 2005) which rose to #1 on Amazon's science and math rankings. His articles have been published in various popular outlets, including the *Wall Street Journal* and *New York Times Magazine*. Mills is also a frequent guest on CNN, FOX, NBC, and PBS, and has appeared on *The Daily Show with Jon Stewart*.

Earlier, Mills was a technology adviser for Bank of America Securities, and a coauthor of a successful energy-tech investment newsletter, the *Huber-Mills Digital Power* Report. He has testified before Congress and briefed many state public service commissions and legislators. Mills served in the White House Science Office under President Reagan, and subsequently provided science & technology policy counsel to numerous private sector firms, as well as the Department of Energy and several U.S. national research laboratories.

Early in his career, he was an experimental physicist and development engineer, working at Bell Northern Research (Canada's Bell Labs) and the RCA David Sarnoff Research Center on microprocessors, fiber optics, missile guidance, nuclear energy, and non-proliferation. Mills earned several patents from his work in these fields, and holds a degree in physics from Queen's University, Canada.

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INTRODUCTION

> "We see the distinctive stuff that modern economies are made of: It is ideas. The visible 'goods and services' of the national income statistics are mostly embodiments of past ideas."
>
> —**Edmund Phelps**, 2006 Nobel Prize in Economics[2]

Society-moving revolutions emerge from new ideas. Basic insights in science and mathematics led to the computer age and the Internet. The same can be said about many domains, from photovoltaics, the subject for which Albert Einstein received his Nobel Prize in 1905, to the genetic code, for which Cambridge scientists Watson and Crick received their 1962 Nobel.

Ideas eventually become innovations "embodied" as practical products and services, through spending on applied research and development, and then from commercial investments. But the roots of most world-changing innovations are found in transformative ideas, not in applied research directed at, say, improving the efficiency of jet engines or smartphones. As President Obama briefly noted in his 2014 State of the Union address, more "basic research … can unleash the next great American discovery."[3]

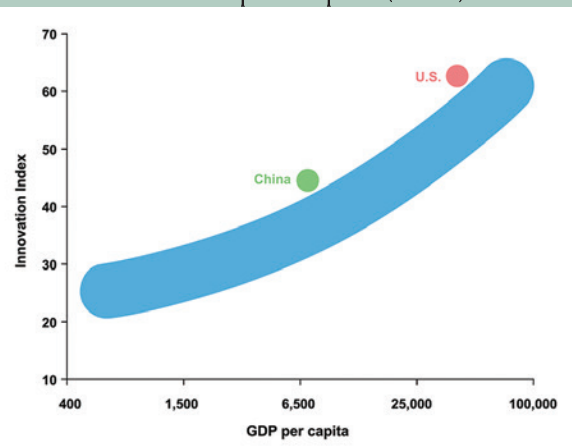
Governments have long played a central role in supporting basic research. At present, almost 90 percent of all basic research in the U.S. is paid for by the federal government. And while the U.S. remains the world's leading supporter of research, it is now on track to lose its decades-long edge. At stake is not mere prestige but the erosion of America's foundation of innovation—and thus, a deep, inevitable long-term weakening of the economy.[4]

A deep body of academic research[5] (epitomized by economist Robert Solow's Nobel-prize-winning work),[6] bipartisan sentiment, and public opinion all embrace the core proposition that advancing technology and innovation are vital for economic growth and broad societal benefits.[7] In fact, technological innovation offers policymakers the closest thing to a "free lunch."[8] Consequently, governments and businesses around the world collectively invest $1.6 trillion annually in all forms of R&D; the U.S., the single biggest player, spends nearly $500 billion, while China's total approaches $300 billion.[9] As **Figure 1** reveals, at the national level, innovation directly correlates with wealth.

But in the context of a $17 trillion economy, is U.S. spending adequate? And are its investments in the right places—specifically, is a sufficient amount of total R&D spending going to basic research? Two broad trends offer guidance.

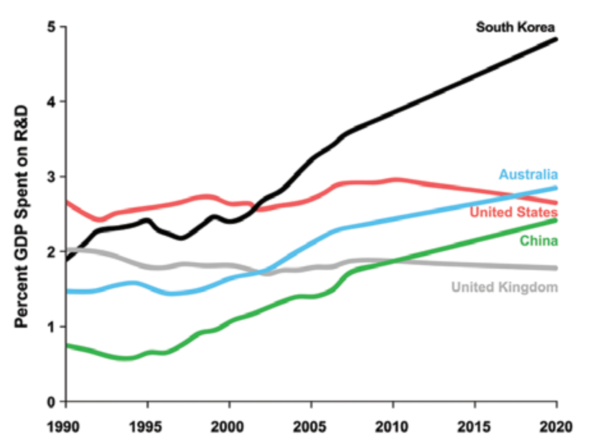
The first is that America is falling behind global trends in overall R&D spending (**Figure 2**). In major competing countries, a rising or stable share of GDP is devoted to overall R&D spending (counting everything, including basic and applied research in all domains—private, public, defense, nondefense), while the U.S. GDP that is devoted to R&D declines.

Figure 1. Relationship Between Innovation and GDP per Capita (USD)



Data source: 2014 Global Innovation Index[10]

Figure 2. Global Trends in Total R&D Spending*



*Includes all sources of funding: public, private, defense, and nondefense
Data source: Information Technology & Innovation Foundation[11]

Second, many policymakers are increasingly impatient for research to yield practical solutions to age-old problems—from better food and fuel to disease cures—as well as to new ones, such as terrorism and cybersecurity. Accordingly, federal R&D spending has been increasingly directed to narrow interests, specific disease problems, or specific products (such as solar panels and batteries).

Solyndra and A123, failed solar and lithium battery companies, respectively, were prominent among numerous such firms that received large grants and low-cost loans from the Department of Energy, an agency that is among the biggest federal R&D funders. Such projects were not used to advance basic science in photo-electricity or lithium chemistry but rather as public-sector venture funding of U.S. businesses to compete with (mainly Chinese) foreign competition. Such politically directed spending has totaled billions of dollars, with an ignominious track record of subsequent and quick failures. Despite such failures, many policymakers cling to the view that "this kind of investment must continue."[12]

Nevertheless, bureaucratized venture capital is fundamentally misguided: among other reasons, focusing federal spending on applied research and commercial-scale projects puts the U.S. government in direct competition with the private sector, where spending on applied and project-specific R&D is ten times greater.

Moreover, when the federal government tries to ape private-sector applied R&D, basic research loses out. Imagine the unhappy result if, in 1945—at the dawn of the modern era of federal support for R&D—instead of fostering and funding a world-class basic research ecosystem, the U.S. had devoted federal R&D on near-term applications of then-known knowledge and technology.

This paper outlines how U.S. government research spending has evolved, and it proposes remedies to the growing problem of declining support for basic research.

I. ORIGINS OF GOVERNMENT SUPPORT FOR R&D

"The economic arguments for government support of innovation generally imply that governments should focus particularly on fostering basic, or foundational, research."
—**Ben Bernanke**, former Federal Reserve chairman[13]

Until recent history, the "science" in science and technology (S&T) was almost entirely found in the domains of academe and was not, as it is today, an integral part of "technology" used to solve practical problems and to achieve economic, social, or military goals.

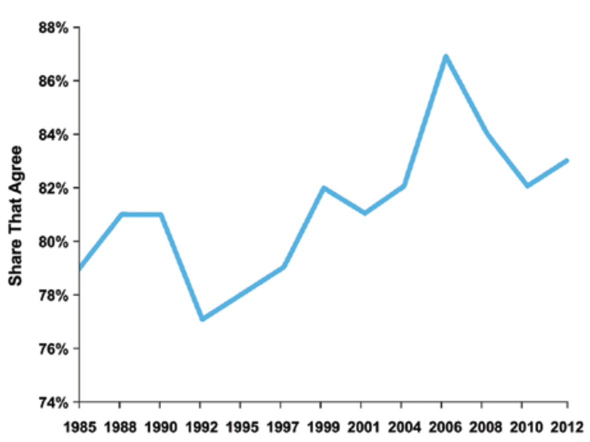
Even so, scientists have long recognized the utility of advancing basic knowledge. In 300 BC, Euclid observed that his domain of mathematics had practical value for such things as "arranging artillery" and "compounding medicines."[14] Among numerous examples, a sixteenth-century astronomer, who earned a living as a consultant to Queen Elizabeth, helped construct Dover Harbor.[15] The progenitor of modern computing, mathematician Alan Turing, was put to work in World War II on the practicalities of breaking the Nazi code, while the great theoretical physicist Freeman Dyson was tasked with the logistics of aerial bombing.

But it was during World War I that the institutionalization of science within the machinery of government began.[16] In 1916, America's National Research Council (NRC) was created by an astronomer to "promote the national security and welfare."[17] However, it was not until World War II that the modern "science-government complex" came into existence. Vannevar Bush, director of the (now-abolished) federal Office of Scientific Research and Development, who wrote in 1945 that there was still "no national policy for science," is widely credited as the architect of modern federal R&D policy.[18]

Following Bush's leadership, the U.S. subsequently emerged as the world's dominant player in S&T. Consider two iconic indicators: (i) American residents or citizens have been awarded more than half of all Nobel prizes in science, medicine, and economics;[19] and (ii) America is home to 34 of the world's top 50 universities.[20] Meanwhile, surveys over the decades show that Americans hold science and scientists in high regard,[21] with a substantial (and rising) majority supporting federal R&D spending (**Figure 3**).

From inception, however, the "utility" of S&T was central to garnering political and financial support.

Figure 3. Share of U.S. Population Supporting Federal Funding for R&D



Data source: National Science Foundation, Science & Engineering Indicators 2014[22]

"The Government," wrote Bush in 1945, "has only begun to *utilize* [emphasis added] science in the nation's welfare." In emphasizing utility, Bush also unintentionally set into play ideas that today undermine the future of basic research. For, as we shall see, the more tightly that funding is tied to immediate utility or specific applications, the less spending is devoted to potentially transformational basic research, in government and university laboratories.

II. TYPES OF R&D: IMPORTANCE OF TAXONOMY

"The reason that we do basic science is to understand how the universe works, and what our place is within the universe. It is a noble quest."
—**Paul Davies**, theoretical physicist, cosmologist, and astrobiologist[23]

Paul Davies is, of course, correct: basic science is a noble quest. But many people, as well as most businesses and governments, demand more than this. The federal Office of Management and Budget (OMB) classifies research into three groups that can be summarized as:[24]

- *Basic*. Research directed "toward fuller knowledge or understanding … without specific applications toward processes or products in mind."
- *Applied*. Research addressing "a recognized and specific need."
- *Development*. Research for "the production of useful materials, devices, and systems or methods."

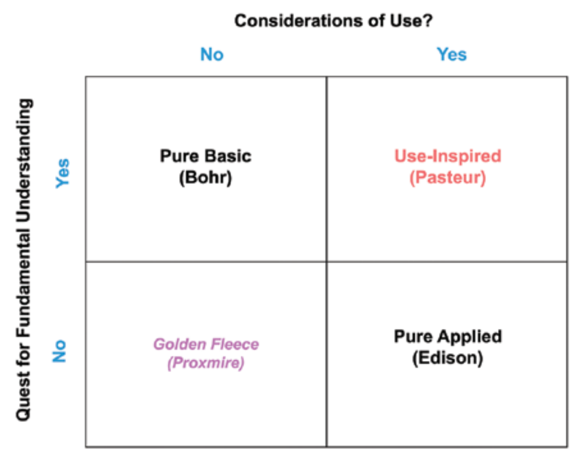
This taxonomy encourages a linear way of thinking: basic research yields knowledge that is then made practical in applied research, followed by the development of a product. In this model, support for basic research is not bottom-up—seeking new knowledge in a noble quest—but top-down in the pursuit of desired outcomes, solutions, or products. Alas, a top-down model is (typically) neither how the R&D ecosystem works in practice, nor (especially) how foundational ideas emerge.

Pasteur's quadrant (**Figure 4**), another similar and popular way to frame R&D, is a model based on two binary questions on knowledge and utility.[25] Its quadrants feature iconic names: physicist Niels Bohr, who, circa 1913, ostensibly sought only to understand atomic structure, without consideration of utility; chemist and microbiologist Louis Pasteur, who sought to understand as well as cure disease; and entrepreneur Thomas Edison, the Steve Jobs of the nineteenth century, who just pursued products.

Binary and linear taxonomies both fail to reflect dynamic reality, and they infect public policy formulation. After all, why would anyone spend a dime on anything other than outcome-based R&D—if one could know precisely where to pursue useful ideas—or on what appears to be a win-win ("yes-yes") quadrant?

Meanwhile, history is replete with examples of the pursuit of pure knowledge unintentionally yielding practical and sometimes world-changing products. The astronomer George Ellery Hale, who would in 1916 found the NRC, was curious about what stars were made of and invented spectroscopy, subsequently an enormously useful industrial tool.[26]

Figure 4. Pasteur's Quadrant*



*Donald Stokes, a political scientist who coined the concept, left the bottom-left quadrant blank. Here, instead, we label it for Senator William Proxmire (D–WI), who, in 1975, created a Golden Fleece Award for wasteful federal research. First "awarded" to the National Science Foundation for a study on why people fall in love, the Golden Fleece officially ended with Proxmire's 1989 retirement, though many scientists still fear being "Proxmired" by popular/media misunderstanding of research.

Source: Donald E. Stokes, *Pasteur's Quadrant* (Washington, D.C.: Brookings Institution Press, 1997)

Theoretical mathematics developed by Pascal and Fermat in the seventeenth century yielded the revolution in probability statistics universally used today.[27] When Watson and Crick identified the structure of DNA in 1953, they were not seeking to develop a better way to improve the justice system.

For a more recent, representative example, consider UC Berkeley biologist Randy Schekman. Schekman and his team were curious about how molecules in yeast proteins operate and "had no notion of any practical application." Since humans have long used yeasts to make bread and beer, such research might have seemed the proper domain of brewers and biofuel companies. Yet that research, in garnering a 2013 Nobel Prize, ended up also providing the road map for the biotechnology industry to manufacture one-third of the world's human insulin.[28]

Similar examples of productive serendipity abound. Undirected research in the molecular basis of neurotransmitters resulted in practical uses of poisonous botulism bacterium to treat neuromuscular diseases and paralysis (as well as its use in Botox). Chemist Edward Taylor's famous study of butterfly wings led to the development of cancer therapeutics (the royalties from which funded a new Princeton University chemistry building).[29]

There is Serge Haroche, 2012 Nobelist in theoretical physics, whose insights may hold the key to quantum computing (which, when it happens, will be equivalent to the invention of digital computers themselves). "The major technological breakthroughs," observed Haroche, "have come from basic research which wasn't originally conducted for that purpose—progress just happened, because researchers were curious about nature."[30]

Most basic research, of course, doesn't immediately or necessarily lead to practical outcomes. Inversely, applied industrial research can lead to unintentional advances in basic knowledge.

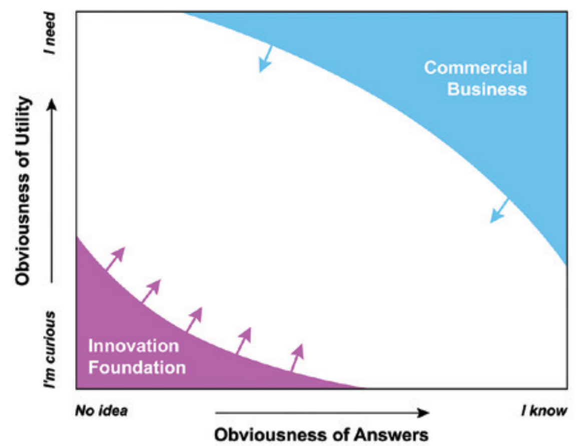
Watt invented the steam engine to improve coal mining—prompting Sadi Carnot's promulgation of the foundational laws of thermodynamics. Arno Penzias and Robert Wilson of Bell Labs, in pursuit of superior commercial radio antennae, revealed the universe's cosmic background radiation—ending debate over whether the universe began with a Big Bang (garnering the duo a 1978 Nobel).[31] Antibiotics emerged from Alexander Fleming's gritty experience in World War I field hospitals and, after, in clinics.

Accordingly, **Figure 5** proposes a different taxonomy of R&D to better reflect the dynamic continuum of "utility and knowability"—named herein the Haroche-Schekman Continuum, in recognition of the two aforementioned Nobelists for their call to action to revitalize basic research.

The dynamism and interplay of the overall R&D ecosystem across the Haroche-Schekman spectrum produces transformative results.[32] Basic research, activities in the "innovation foundation" with inherently indeterminate outcomes, naturally faces the greatest challenge of all for funding.[33]

Scientists have long been aware of demands for practical outcomes from indeterminate research. In the

Figure 5. Haroche-Schekman Continuum



Note: On the utility (y) axis, the question "how do proteins behave in yeasts?" is quite different from "how can I manufacture human insulin?" Moreover, there are rarely simple binary, yes-no answers. Commercial businesses are more likely to spend money in the top-right zone. In the bottom-left zone, one expects to find basic, or academic, inquiry. The internal arrows represent the tendency for migration between the two zones.

Source: Mark P. Mills

eighteenth century, when the great physicist Michael Faraday's curiosity led to the discovery that a magnetic field could induce an electrical current in a wire (i.e., a motor or generator), popular history records that the British Chancellor of the Exchequer, on seeing the experiment, inquired, "Of what possible use [is] it?" To which Faraday is apocryphally reported to have quipped, "Why, one day, you shall tax it, sir."[34]

III. THE STATE OF R&D IN AMERICA

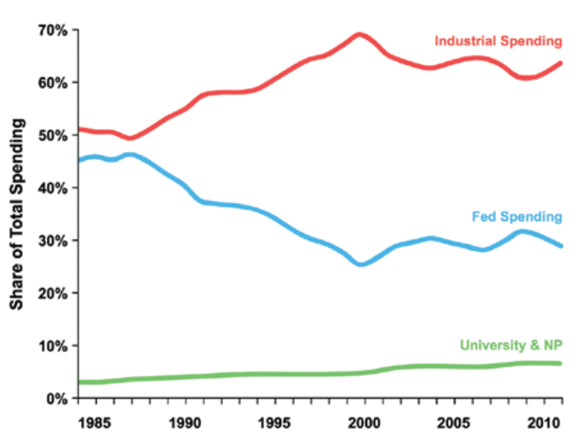
"The balance has tilted, making us focus too little on basic research, and I think that's dangerous. We have to protect basic research if we're to have scientific breakthroughs in the future."[35]
—**Serge Haroche**, 2012 Nobel Prize in Physics

Today, the world faces arguably no fewer challenges than it did six decades ago, at the dawn of the modern era of the science-government complex. Transformative new technological solutions await, as in the past, fundamental advances in basic knowledge and science.

The state of R&D, however, has changed over the decades in ways that illustrate the warnings of Haroche and Schekman and that illuminate possible solutions. Key changes include:

- Industry, not government, has emerged as the primary spender.
- Federal funding is now highly concentrated in a handful of powerful agencies.
- There has been a general drift away from basic research.
- A hyper-focus on health research has come to dominate funding.
- Ever less federal funding goes to younger researchers.
- Funding is increasingly concentrated in the hands of fewer "rich" researchers.
- Scientists' time has become heavily bureaucratized.

Figure 6. Total U.S. Nondefense R&D Spending



Data source: National Science Foundation

The Emergence of Industry as the Primary Spender

Private-sector spending on research has been rising continually ever since corporations, roughly a century ago, adopted the concept of an R&D division. Beginning several decades ago, business spending rose sharply and now accounts for about two-thirds of total U.S. R&D funding (**Figure 6**).

On top of that, 40 percent of federal R&D outlays go to industry. Consequently, about 80 percent of all U.S. R&D spending takes place within the industrial sector. The rest of federal R&D spending is deployed, in roughly equal shares, to federal labs and universities,[36] both of which increasingly focus on application-directed projects.

The bottom line: the major share of R&D money is now associated with industry.

Federal Funding Is Highly Concentrated in a Handful of Powerful Agencies

The federal government's civilian research funding is spread across 29 agencies and departments. Diversity of decision making in basic science is arguably a good idea. However, 90 percent of all federal R&D (non-DOD) spending is controlled by a mere five agencies (**Figure 7**):[37] National Institutes of Health (NIH), Department of Energy (DOE), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), and Department of Agriculture (DOA).[38] Such agencies' support for basic research has stagnated or declined (see next section).

Bottom line: just five agencies—and thus a small number of bureaucrats—control decisions on nearly all federal R&D spending.

A Drift Away from Basic Research

In recent decades, as the combined amount of private and public money devoted to applied R&D has risen substantially, the amount spent on basic R&D has not only stalled but has started to decline (**Figure 8**).

That industry funds the majority of R&D has obvious implications for allocation decisions between short-term application-centric and long-term curiosity-centric research. Less than 5 percent of private-sector R&D spending is directed at basic research, a share similar to that associated with the Department of Defense R&D budget (**Figure 9**).[40]

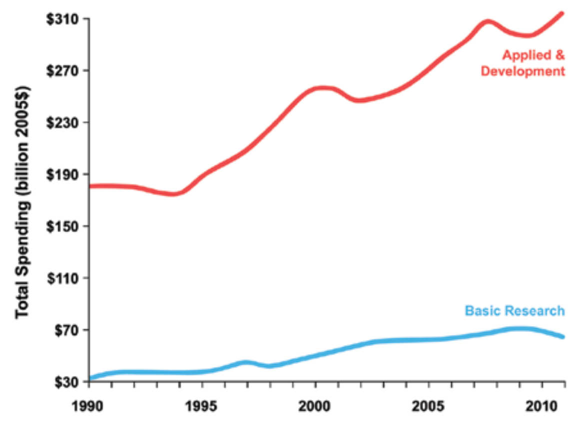
Figure 7. Share of All Federal Civilian R&D Funding by Agency

Agency	Share, %	
NIH	45.54	90%
DOE*	16.70	
NASA	14.25	
NSF	8.51	
DOA	3.53	
Veterans Affairs	1.76	
HHS (non-NIH)	1.66	
Transportation	1.43	
Interior (USGS)	1.02	
Homeland Security	0.94	
Commerce (NOAA)	0.88	
EPA	0.86	
Commerce (NIST)	0.84	
Education	0.59	
Smithsonian	0.37	
Interior	0.18	
Int'l Assistance Programs	0.18	
Patient-Ctr. Outcomes	0.18	
Justice	0.14	
Nuclear Reg. Commission	0.13	
State	0.11	
HUD	0.09	
TVA	0.02	
Postal Service	0.02	
Corps of Engineers	0.02	
Social Security	0.01	
Labor	0.01	
Telecom	0.01	
Consumer Prod. Safety	0.01	

*DOE R&D falls under three main program areas: 20% energy, 40% science, and 40% DOD nuclear support. (Strictly speaking, DOD support is not civilian R&D: excluding the latter reduces DOE's share of civilian R&D to 10%, with the top five agencies accounting for 84% of all civilian R&D, respectively.)

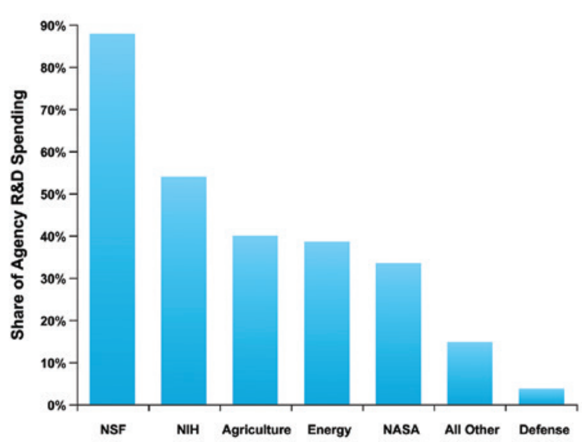
Source: American Association for the Advancement of Science[39]

Figure 8. U.S. Trends in All Private and Public Nondefense R&D Spending*



*All nondefense spending on basic and applied research
Data source: National Science Foundation

Figure 9. Federal Agencies' Allocation of Spending on Basic Research*



*Each federal department or agency with an R&D operation self-identifies the share of spending claimed as "basic."
Data source: American Association for the Advancement of Science[41]

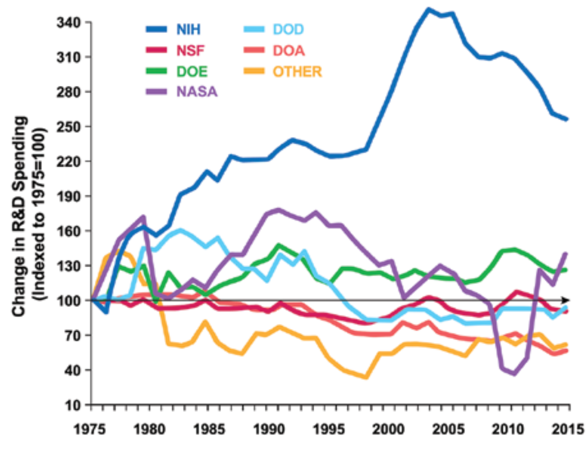
Combining data series for Figures 8 and 9, we see the trends in spending on basic research—measured in terms of each agency's budget as a share of U.S. GDP (**Figure 10**). In all 29 federal R&D agencies except one (NIH), spending on basic science has been essentially flat or in slow decline for several decades.[42] (The NIH itself has seen a decline over the past decade.)

Bottom line: the share of R&D money directed at basic research has declined.

A Hyper-Focus on Health-Related Research

The share of federal research dollars allocated to health-related areas has been rising for decades. At the same time, there has been a steady decline in federal support for all other research areas, combined (**Figure 11**). The relative positions of the budgets of NASA and NIH have reversed: in effect, the U.S. has traded its federal research emphasis on outer space for "inner" space. (Indeed, much of how NASA currently utilizes its instruments involves pointing them not outward but back toward Earth, to further earth and climate science.)

Figure 10. Trends in Basic Research Spending as a Share of GDP*

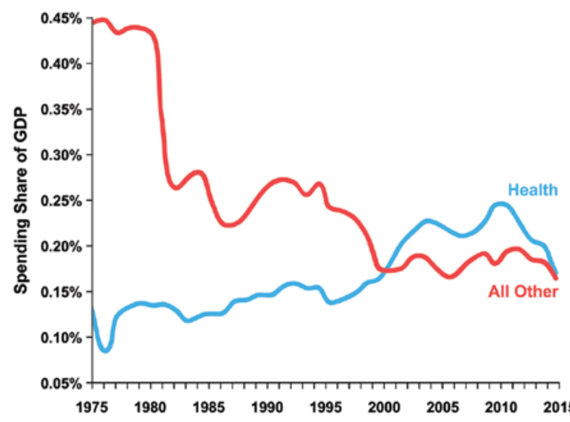


*As a reference point: U.S. GDP has grown 300 percent in constant dollars since 1975.

Acronyms: National Institutes of Health (NIH); National Science Foundation (NSF); Department of Energy (DOE); National Aeronautics and Space Administration (NASA); Department of Defense (DOD); Department of Agriculture (DOA); all other agencies with an R&D budget (Other).

Data source: American Association for the Advancement of Science[43]

Figure 11. Total Nondefense Federal R&D as a Share of GDP, Health vs. Non-Health



Data source: American Association for the Advancement of Science[44]

From 1998 to 2003, NIH's budget doubled, but has since declined by about 10 percent (excluding the one-year stimulus grant of about $10 billion); NSF's budget, the largest source of non-health basic R&D, has been essentially flat for over a decade (again, except for the one-time $3 billion stimulus infusion).

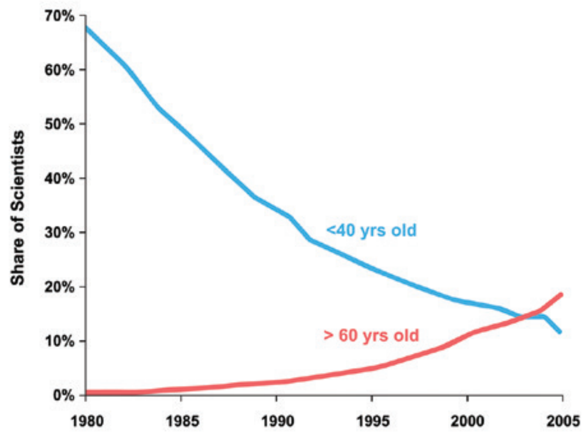
Bottom line: health-related research has grown to dominate all other domains *combined*.

Younger Researchers Are Losing Out on Federal Funding

Data from the NIH, the largest nondefense federal R&D entity (and for purposes herein, a proxy for overall R&D spending, given the commonality of federal procedures), show that over the past three decades, as the total number of awards distributed has doubled, the total given to scientists under the age of 35 has dropped by over 40 percent.[45] The average age of NIH-funded researchers has risen from 40 to 50, while the share of researchers over 60 is now greater than that for those under 40 (**Figure 12**).[46]

The aging demographic of NIH research award recipients is far more extreme than the general aging of the U.S. population: since 1980, America's median age has risen from 30 to 37. Aside from ensuring that the next generation of scientists have jobs, the im-

Figure 12. Share of NIH Researchers over 60 vs. Under 40



Note: This trend may be driven in part by grant criteria that favor applications from research teams that are often led by senior (and thus older) researchers, and thus leave uncounted many on the team who could be younger. Data available don't provide insights on this "internal" dynamic; but even if it were the case, the younger researchers would be undertaking research directed by the senior manager and not self-directed, or curiosity-driven, inquiry of their own.

Data source: *Restoring the Foundation* (Cambridge, Mass., American Academy of Arts & Sciences, 2014).

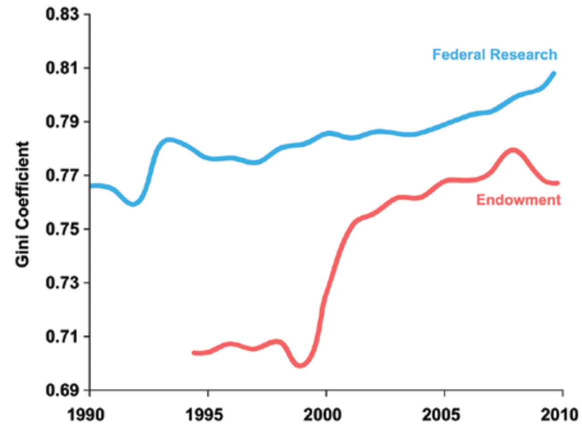
portance of supporting young researchers is revealed in a number of studies correlating age and scientific creativity. One study of more than 2,000 Nobel Prize winners and scientists found that a majority of Nobelists were aged 35 to 39 when they discovered their key idea.[47] Another analysis of the Nobelists showed "great achievement" commonly before 45 years of age.[48]

Bottom line: federal funding for young researchers has declined radically.

Rewarding the Rich

Federal funding is increasingly awarded based on a formulaic accounting of a researcher's track record, such as number of publications, citations, previous grant wins, recognition awards, and team size. While metrics can reduce bureaucratic favoritism and qualitative judgment, their rigid application has resulted in the awarding of an ever-rising share of funding to a small group of established, usually older and already well-funded, researchers (**Figure 13**).

Figure 13. Increasing Concentration of Research Funding*



*The Gini coefficient (pioneered in 1912 by Italian statistician Corrado Gini) measures inequality distributions in income or wealth: a zero identifies absolute equality, and 1 maximum inequality.

Data source: Science, 2014[50]

Robert Merton, founder of the sociology of science, labeled this the "Matthew effect" (after the biblical injunction "For to all those who have, more will be given, and they will have an abundance; but from those who have nothing, even what they have will be taken away").[49]

In general, a growing number of researchers are applying to a fixed, or shrinking, federal budget pool—leading to a declining success rate for applications. At the NIH over the past decade, applications have risen from 50,000 to 80,000 annually, while the share winning an award has dropped from 32 percent to 17 percent. At the NSF, applications rose from 35,000 to 50,000, with the success rate falling from 32 percent to 22 percent.[51]

Bottom line: federal research funding is increasingly unfair and subject to winner-takes-all.

The Bureaucratization of Research

A rising tide of regulations and paperwork is crushing researchers (**Figure 14**). A 2014 survey of more than 13,000 U.S. scientists found that, in addition to work associated with producing proposals and reports for federally funded research, researchers are typically required to complete at least 23 other types of bureaucratic tasks.[52]

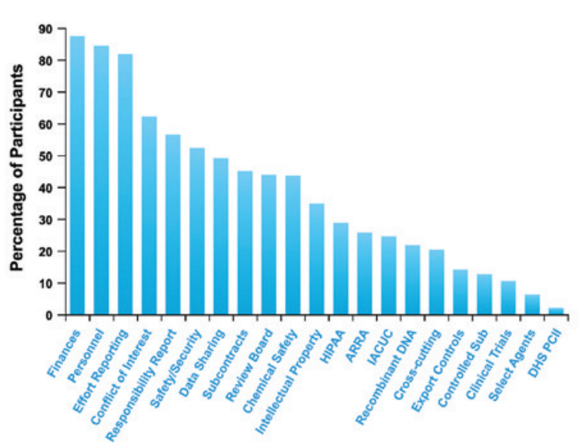
This administrative workload, the survey found, has increased over the past half-dozen years. Researchers now spend nearly half their time performing administrative tasks rather than conducting actual research.

In addition, survey respondents identified a half-dozen other bureaucratic burdens:

- Risk-intolerant audit and legal culture
- Changes, ambiguities, and inconsistencies
- Overwhelming forms and paperwork
- Unnecessary, ineffective training
- Problematic electronic systems and forms
- Rigidity and micromanagement

The same survey also found that scientists worried that bureaucracy would not only discourage students from pursuing academic research careers but that it was undermining "the fundamental ability to conduct high quality research." (Anecdotal evidence and operational experiences suggest that these nanny-state trends are, perhaps, even more severe than official surveys reveal.)[54]

Figure 14. Bureaucratic Workload for Researchers Receiving Federal Funds*



*Share of scientists—in a survey of more than 13,000—reporting responsibility for an administrative task consuming "significant" time

Data source: Federal Demonstration Partnership[53]

Bottom line: the bureaucratization of federal R&D is discouraging scientists and squandering resources otherwise useful for advancing science.

IV. WHY FEDERAL CIVILIAN R&D HAS CHANGED

"[The Nobel prizes] reflect the value of curiosity-driven inquiry, unfettered by top-down management of goals and methods.... And yet we find a growing tendency for government to want to manage discovery with expansive so-called strategic science initiatives at the expense of the individual creative exercise we celebrate today."[55]
— **Randy Schekman**, 2013 Nobel Prize in Chemistry

Both the Great Recession and Sequester of 2013 led to reductions in federal R&D budgets. The latter forced decreases in "discretionary" government spending (as opposed to "entitlements," such as healthcare and Social Security), including R&D. Nevertheless, the drift away from federal support for basic research had begun at least a decade or two earlier.

Rationale for federal support for basic research is, as discussed, rooted in the reality that such endeavors are inherently long-term, often nonspecific, and subject to the tragedy of the commons. As Ben Bernanke recently observed, "the full economic value of a scientific advance is unlikely to accrue to its discoverer, especially if the new knowledge can be replicated or disseminated at low cost."[56] It is this reality, more than others, that underlies the disincentives for corporate spending on basic research. Indeed, all three features of basic research—long horizons, non-specificity, and the common benefit of knowledge—present a core challenge not merely for private-sector support of basic science but for federal support, too.

Several major trends have helped diminish support for basic research:

- The lure of commercial, near-term value
- An expanding nanny state to police and control scientists and their funders
- The growth in politicians' pet programs, especially the launching of appealing "initiatives"

- Rising pressure for social policy to take precedence over solid science
- The lure of the Silicon Valley model

Commercialization

Basic research is inherently noncommercial. Nonetheless, in both good and bad financial times, supporters of basic research are subject to calls for clear—and even near-term—applicability. There is always a vocal chorus demanding research to solve various issues, particularly those articulated in media and activist circles—from specific diseases, to resource depletion, to climate change.[57]

Private individuals, nonprofit organizations, and businesses furiously lobby Congress and federal agencies, arguing for greater support for particular research needs. Thousands of single-disease-specific nonprofits now operate, a phenomenon that emerged only several decades ago. Spending by such groups on disease-specific lobbying has nearly tripled in the past two decades. The data show that it (as with all forms of lobbying) is effective.[58]

Witnesses at congressional hearings are now twice as likely to be from a disease-lobbying organization as from a health organization, a complete reversal of the situation several decades ago. Such change has had an impact: data—tracking the efforts of thousands of disease-specific lobbying teams over the past two decades, on 53 different diseases—reveal that every $1,000 spent on lobbying correlated with a $25,000 increase in funding the following year.[59]

Trade literature in every domain, not simply that of diseases, is filled with project- or problem-specific proposals urging more federal R&D for the various fields. In general, engineering-centric projects are garnering an increasing share of basic science budgets.[60] One prominent venture capitalist called for the White House to launch an Apollo-like program to conquer the endemic challenge of cybersecurity.[61]

Going to the moon had great symbolic, strategic, and scientific value. But President Kennedy did not launch the mission to ensure that citizens enjoyed GPS navigation and better weather forecasting (though both were directly derivative). Today, many groups nevertheless desire still more federal spending on, say, renewable energy research. "Wouldn't it be great," remarked one such prominent advocate, "if governments and energy companies adopted a similar approach [to the private sector] in their technology R&D investments?"[62]

When it comes to basic science, the answer is clearly no. Funding commercial solar-power plants, for example, won't lead to the discovery of foundationally superior classes of photovoltaic materials. The present trend, rather, is essentially the conversion of R&D policy into industrial policy. There can be real value in applied research directed at specific problems, but it is decidedly not basic science.

Nanny State

When money and power increasingly concentrate in the central government—where virtually all basic research spending currently originates—the standard response rarely involves reducing such concentration and redistributing funds but rather, further centralizing authority. As federal institutions continue to bloat, with associated challenges for management and oversight, bureaucracies typically layer on means to direct spending and to monitor activities to minimize frivolousness and fraud. In turn, reporting, documentation, and regulations bloat.

Nor is it only researchers; the federal funding agencies themselves also face episodic (as opposed to continual) scrutiny. Congressional committees charged with agency budget oversight occasionally examine whether research money benefits the well connected, or supports purely politically motivated projects. In fact, new legislation is on the table to further restrict how research funds are awarded, motivated by such headlines as "taxpayer money used to study drunken monkeys"[63] and the "discovery" of a nearly $6 million "research" grant to help "educate" communities in the Arctic about global warming.[64]

More rules and oversight are unlikely to solve these endemic problems. Nor is a spirit of cooperation likely to emerge when, for instance, one administration witness asserts in congressional testimony that "I just don't feel that most people in this room are well qualified to second-guess NSF's superb peer review committees."[65] The fundamental problem is that so much decision-making power, over so much money, now rests in so few hands.

Pet Political Initiatives

One irresistible political force is the appeal of creating new, exciting-sounding, tech-centric, or scientifically themed "initiatives." These can be easily justified, based on urgent economic or geopolitical trends. They can also be used to satisfy popular perceptions, political ideologies, campaign promises, or to reward a favored constituency. (Politically motivated civilian pet programs are inherently different from, though are often improperly analogized with, goal-specific military programs: the latter not only have narrow and precise goals but also are not intended to advance basic science or knowledge.)

Pet programs are not new. Kennedy's Apollo program may be the modern grandfather of all such subsequent civilian initiatives. But until recently, pet programs were few in number and often grand in scope. Nixon launched the War on Cancer in 1971; Carter, the successful Hubble Space Telescope, and, in 1980, the ill-fated Synthetic Fuels Corporation (in reaction to the second oil shock of 1979); Reagan's signature program was the Strategic Defense Initiative; Bush 41, the Human Genome Project in 1990.

Under Presidents Clinton, Bush 43, and Obama, special initiatives accelerated.

Clinton launched, among others, a Climate Change Technology Initiative, Partnership for a New Generation of Vehicles, Nuclear Energy Research Initiative, National Nanotechnology Initiative, and HIV/AIDS Initiative. Bush 43 created such programs as a Global HIV/AIDS Initiative, Vision for Space Exploration, Hydrogen Fuel Initiative, American Competitiveness Initiative, and Advanced Energy Initiative (as well as a huge boost to ethanol subsidies).

President Obama's list, lengthier still, includes a Big Data Initiative, Biofuel Initiative, Protein Structure Initiative, Networking and Information Technology Research and Development Program, U.S. Global Change Research Program, BRAIN Initiative, Materials Genome Initiative, Advanced Manufacturing Partnership, National Network for Manufacturing Innovation, National Robotics Initiative, and a Wireless Innovation Fund.

Each additional program requires millions, and sometimes billions, of dollars—funds taken from existing budgets or future appropriations.

One largely unaddressed challenge resulting from pet programs and associated funding pile-ons is the potential to create groupthink bubbles. Centralized decision making in setting research priorities increases the human tendency for herd mentality and dilutes intellectual diversity. R&D is no less susceptible to this than are the fields of finance and fashion.[66]

Social, Not Scientific, Goals

The scale of the overall U.S. private and public R&D ecosystem—with spending and indirect economic impact combined at over $1.2 trillion annually and 9 million people directly and indirectly employed[67]—increasingly invites pressures to ensure socially desirable outcomes related to job creation, educational strategies, gender, race diversity, disabilities, and "fairness."

One activist, for example, has proposed a Diversity Index to measure "inclusiveness in the science and technology workforce," claiming that "diversity goes to the heart of how to do research and innovation effectively."[68] The merits of "inclusiveness" aside, it is certainly disputable whether better knowledge and transformational advances in basic science will emerge because of diversifying funding on such a basis. (It is also an emotionally charged issue: when one research team published evidence that academic science was not sexist,[69] it was subjected to vicious attack.)[70]

While there may be legitimate reasons to encourage "social justice" in society at large, there is no historical evidence whatsoever that subjecting research to social-justice-based rules will produce solid science.

The Silicon Valley Model

Politicians and their constituents increasingly analogize all forms of R&D with the innovation that has emerged from Silicon Valley. Likewise, many successful Silicon Valley executives, entrepreneurs, and financiers call for a more Silicon Valley–like approach for federal R&D. As appealing as this may seem, this trope is anchored in two misconceptions.

The first is confusion over Moore's Law (named after Intel cofounder Gordon Moore, who, in 1965, predicted that computing power would roughly double every two years) and the torrid pace of advance witnessed in computing and communications. In reality, information technology is not representative of how science—or other technologies, for that matter—progress. Rather, IT has created an entirely new kind of industry and is creating a new class of tools available for researchers.

The second misconception involves the "iPhone effect," the idea that the incredible pace of engineering advances in smartphones suggests that a similar pace of innovation is possible, and can be achieved, everywhere. This notion confuses engineering and science, with the latter advancing far more slowly than the former. For all the value and excitement created by Silicon Valley, it is a community focused on engineering, not basic research. Indeed, much of what made possible the engineering marvels produced in the Valley emerged from basic research elsewhere—notably, the work of Nobel-class scientists, dating back many decades. (It is true that some of Silicon Valley's wealth is now finding its way into basic research, though mainly through acts of individual philanthropy, not corporation spending.)

V. DOES THE PRIVATE SECTOR FUND BASIC RESEARCH?

"Modern progress can no longer depend upon accidental discoveries. Each advance in industrial science must be studied, organized, and fought like a military campaign."[71]
—**Arthur D. Little**, 1913 American Chemical Society annual lecture

Today, corporations spend more than four times as much on R&D as all federal programs combined (excluding defense). But when it comes to basic research, industry spending is less than half that of the federal government.[72]

Even the most lauded corporate innovators are not focused on basic science but on engineering projects, such as Google X's self-driving cars and drones. Similarly, Google's Advanced Technology and Projects group is focused on applications with a two-year deadline, which, by definition, bears no resemblance to the kinds of timelines associated with long-term, knowledge-centric inquiry.[73] A 2014 survey of business leaders reported rising pressure for a results-centric focus on such funding.[74] As for the $30 billion spent annually by U.S. venture capital firms to "translate" innovations into new products and companies, none of this, by definition, is directed at basic research.[75]

Private-sector spending on R&D can be divided into three classes:

1. Productivity and Profits
2. Prizes and PR
3. Philanthropy

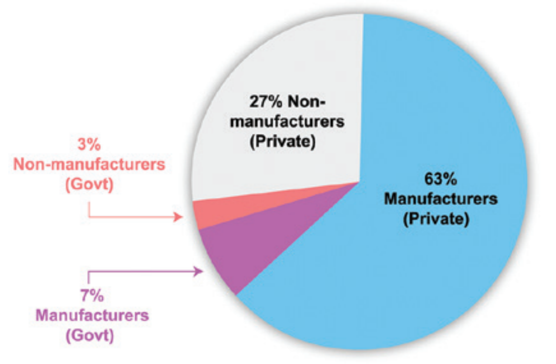
As currently pursued, the first two classes are almost entirely associated with applications. Only the third has significant engagement with basic research.

Productivity and Profits

Leadership in research is a frequent tool used to burnish corporate reputations. Applied R&D spending also correlates positively with revenues and profits.[76] As **Figure 15** illustrates, the manufacturing sector is the biggest R&D spender, with the federal government directly funding about 10 percent of industrial R&D.

The era of the big corporate lab—epitomized by Nobel-winning teams at once-vaunted Bell Labs—seems to have come to a close, even though IBM, GM, Exxon, and others maintain substantial R&D divisions.[78] It remains to be seen if new tech-centric leaders (such as Google, Microsoft, Facebook, and Intel), with their huge cash hoards, will yet support

Figure 15. Industrial R&D Spending: Manufacturers vs. Non-Manufacturers



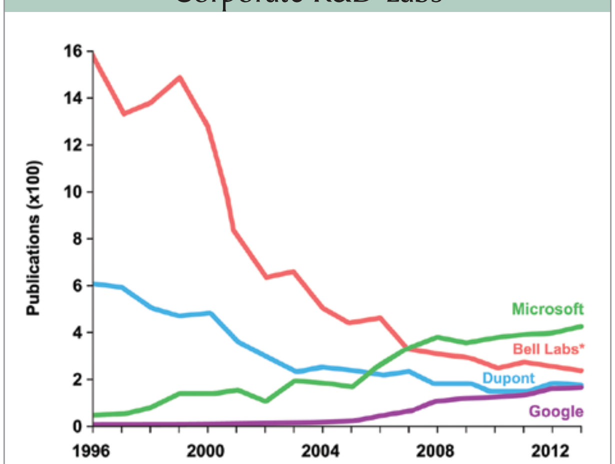
Data source: "Making Innovation," *MIT Technology Review*, 2014[77]

a similar class of basic science discovery as did the corporate giants of the post–World War II R&D era. **Figure 16** depicts this changing of the corporate guard, as measured by four iconic firms.

Prizes and PR

Prizes have become more popular both for corporate PR tools and for stimulating innovators—and recently, popular as a PR tool for federal agencies as well. Contests have proliferated in the past decade, and total prize money has tripled. Corporations account for about 30 percent and nonprofit foundations 50 percent of all prizes.[80]

Figure 16. Research Publications from Corporate R&D Labs



*Currently the R&D subsidiary of Alcatel-Lucent
Date source: Nature[79]

First awarded in 1901, the Nobel Prize remains the gold standard of prizes. Yet businesses—and increasingly, nonprofit organizations, including the Nobel Committee itself—are focusing less on prizes for mere elegance of thought, or for the advancement of ideas, and more as tools for rewarding advances in engineering's domains.

The idea of offering prizes for solving technical problems dates to antiquity. In autumn 2014, on the 300th anniversary of the Longitude Prize—offered by Britain's government in 1714 to solve the problem of navigating the world's oceans—Britain resurrected that storied prize with a $17 million award.[81] (The original award was worth about $2 million in today's dollars.) This time, the public was given the opportunity to vote on the problem to be solved, from clean water to climate change: better antibiotics won. In 1919, it was a private prize ($350,000 in today's dollars) that inspired Lindbergh to make the first solo transatlantic flight.

Technology prizes can be for historic accomplishment or to stimulate a new product. The National Academy of Engineering's annual Draper Prize (first awarded in 1998) focuses on engineering accomplishment. Meanwhile, the DOD's Defense Advanced Research Products Agency (DARPA) is among the most well-known to prompt competitions. Ten years ago, for example, DARPA sponsored a $1 million prize for an autonomous vehicle to navigate a 12-kilometer off-road course.[82] DARPA now is running a robot and cybersecurity challenge, among others.[83]

The White House has jumped on the prize bandwagon, too, creating a web portal for "one-stop shopping" for public-sector prizes. In 2011, it granted broad authority to all federal agencies to "make prizes a standard tool," tapping into a budget authority of "up to $50 million."[84] More than 40 agencies now offer 150 prizes, with awards ranging from $10,000 to $50,000. (Such relatively anemic prizes may explain why the program has not earned the kind of PR bump enjoyed by others.)

The far more visible XPRIZE Foundation, founded in 1995, epitomizes one of the most successful institutionalized private-sector prize structures. XPRIZES range from genomics to landing a robot on the moon.[85] In 2004, a $10 million XPRIZE went to the creator of the first privately developed suborbital space flight, a contest that inspired more than $100 million in collective spending by 26 competing teams. The XPRIZE model, when it works well, is to encourage precisely this kind of "leverage" in stimulating far more private spending than the value of the prize. Numerous other companies have partnered with, or followed, the XPRIZE model.

In 2016, Qualcomm, for example, will announce the winner of its $10 million Tricorder XPRIZE to pursue a real version of the science fiction medical tool from Star Trek.[86] Intel recently awarded $500,000 for its "Make It Wearable" prize.[87] (The winner developed a wristband that transforms into a small, camera-carrying drone.) In 2009, Netflix awarded $1 million for the inventor of a better movie-search algorithm.[88]

While contests can be fascinating, good PR, and episodically useful, the total value of all prizes remains below $400 million—a minuscule share of total R&D.[89] Further, virtually all the new prizes announced since 1991 have been directed at specific products, not to recognize general advances in science or knowledge.[90]

Prizes, in short, have been all about engineering. Google, to its credit, recently announced that it would fund the Turing Award—in effect, a Nobel Prize for computer *science*—at the $1 million level, roughly matching the Nobel level of cash.[91]

Philanthropy

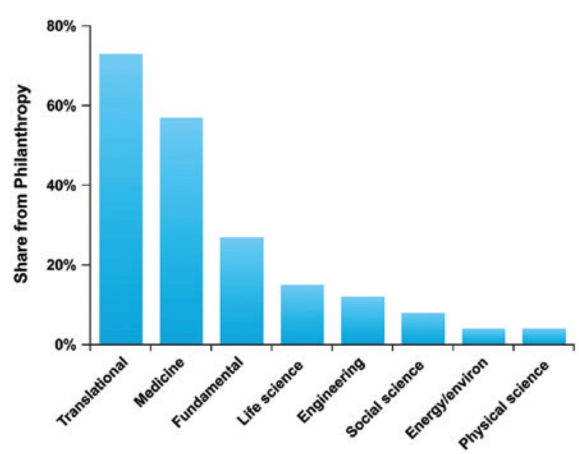
In an era of declining support for basic science, private philanthropy—from foundations, wealthy individuals, and endowments—is a rare bright spot. Indeed, philanthropy is now the fastest-growing funding source, constituting nearly 30 percent of total budgets for university research funding.[92] **Figure 17** reveals philanthropy's share of U.S. university R&D funding, by discipline.

Leading U.S. research universities receive about $7 billion from philanthropic funding, 30 percent of total annual research funds. By comparison, corporations account for less than 6 percent of universities' basic research funding: federal research support, at nearly 70 percent, has stagnated, and state funding has declined to single-digit percentages.[93]

An encouraging note: trends in private philanthropy show a broad-based recognition of, and support for, basic research as essential for future innovation. Consider recent research endowments:[95]

- $1.6 billion to the Ludwig Institute for Cancer Research (donated by the head of a supertanker shipping empire)
- $1 billion for basic research (from James Simons, mathematician and hedge-fund investor)
- $850 million for physics, biology, environment, and astronomy, including $200 million for a new giant telescope (Gordon Moore, Intel cofounder)
- $700 million for genome research at the Broad Institute
- $500 million for medical research (Larry Ellison, Oracle CEO)
- $400 million to the Allen Brain Institute (Paul Allen, Microsoft cofounder)
- $360 million for particle physics, sustainability, and astronomy, as well as $35 million for a giant telescope (George Mitchell, fracking pioneer)

Figure 17. Philanthropy's Share of U.S. University R&D Funding, by Discipline



Source: MIT[94]

- $350 million to the McGovern Institute for Brain Research
- $250 million to the Wyss Institute for Biologically Inspired Engineering
- $165 million to the Stanley Center for Psychiatric Research
- $150 million for cancer studies (Koch Institute)
- $100 million for oceanography (Google's Eric and Wendy Schmidt)
- $100 million for foundational cell biology (Paul Allen)[96]

All told, philanthropy now supports nearly 20 percent of total spending on basic research. Surveys of estate planning by the mega-wealthy reveal that further increases in such funding are coming. Nevertheless, philanthropy's role in basic research remains not only poorly documented but also unlikely, by itself, to reverse the scale of federal funding declines.

In the future, those less wealthy are likely to be able to participate increasingly—and perhaps significantly—in research philanthropy via crowdsourcing.[97]

VI. REFORMING FEDERAL SUPPORT OF BASIC RESEARCH

"If basic research is both a public good and an essential foundation for long-term growth, where can we find the public resources for the sustainable investments in research that the private market will not make?"[98]
—**William Galston**, *Wall Street Journal* columnist

The essential challenge for federal funding of basic science is to strike the right balance between spending money to answer one set of questions (How do we cure cancer? How can we store electricity cheaply?[99] How can we resupply the international space station? How can we eliminate carbon dioxide emissions?)[100] and another (How do proteins operate inside a cell? How can we model quantum electro-chemical behavior? Is there life on Earth-like planets? How does the atmosphere operate?). Managers at the NIH and the NSF are well aware of this challenge. But only Congress has the power to make the kind of foundational changes now required.

In 2015, as Congress legislates on the 60th anniversary of Vannevar Bush's seminal 1945 paper, the state of U.S. government R&D policy is in disarray, facing discord and declining financial support.

Four prominent research leaders from the University of California, Harvard, Princeton, and the National Cancer Institute recently raised the alarm about the need for reform based on the same trends outlined in this report, with a warning that "systemic flaws" are "threatening" America's future science and that we need to "rethink some fundamental features of the US biomedical research ecosystem."[101] Similarly, more than 200 research-university signatories have banded together to lobby for the restoration of all research funding, calling the state of affairs a widening "innovation deficit."[102]

Rather than attempt to restore the old R&D funding order, however, it is time instead for bolder steps and a fundamental restructuring of how America approaches basic research of all kinds.

While Ben Bernanke recently observed that "we know less than we would like about which [R&D] policies work best," we do know what does not work: more central, sclerotic, bureaucratic control.[103] A biography of Michael Polanyi, another world-class economist (and chemist), trenchantly noted that, for Polanyi, "The success of both [economics and the practice of science] required liberty.... ['P]lanned' science would destroy science, just as a 'planned' economy would result in hunger and privation."[104]

The key to a vibrant, intellectually fecund basic research community is diversity—as measured by organizational and management approaches, as well as age, location, and discipline of researchers. The organizing logic for federal funding of basic research should echo the organizing logic of U.S. governance: distribute decisions and control widely. Yet rather than give states authority over dispersal of federal R&D funds (which would leave basic research subject to political pressures), authority should be given to the hundreds of research universities across the nation.

America's basic research enterprise could thus be revitalized by pursuing four core principles:

1. **Decentralize** the federal R&D enterprise, moving most authority to universities for approval and monitoring federally funded basic research.
2. **Incentivize** the private sector to fund more basic research at universities and in their own laboratories.
3. **De-bureaucratize** the grant approval and monitoring process, using modern information tools.
4. **Stop the slide** in federal support for basic research, reducing funding for industrial-class project development instead.

Decentralize Federal Management

The current state of affairs does not call for the creation of a new federal R&D czar or department. Rather, it is time to substantially decentralize the management and administration of basic research.

Instead of five federal agencies making decisions for 90 percent of basic research spending, decisions and control over at least 50 percent of funding should be distributed to hundreds of science-knowledgeable decision leaders. Specifically, research award decisions should be made by the 600 U.S. universities and research institutions—of which more than 100 are major public research universities—that currently receive federal R&D funds.[105]

Congress should distribute such increased funding in the form of undirected block grants for basic, not applied, research, in incremental annual steps, spread over no more than five years. American universities and research institutions are quite able—indeed, more able than the central bureaucracy—to identify, fund, and manage the best and brightest scientists. The remaining 50 percent of federal R&D funding, sufficient to continue significant national-level projects, can remain under the control and distribution of federal agencies (though, as noted below, using less burdensome management tools).

Many important issues would attend implementation, not least of which are: a) selection criteria for identifying and qualifying leading research institutions, while also encouraging the creation or expansion of such; and b) allowing more creative, more varied, and less burdensome approaches to review panels for research selection.

Administrators of universities and research institutions possess ample experience in selecting and overseeing qualified researchers and projects and can do so without heavy-handed federal oversight. For bureaucrats who worry about research being misdirected under such a reform, it is worth keeping in mind that 50 percent of federal R&D funding is now "misdirected"—wasted in performing administrative overhead instead of research. While eliminating picayune federal oversight might theoretically open the potential for misspending, it's inconceivable that such "misspending" would rise to the 50 percent waste now in place. As for episodic instances of malfeasance, there is no evidence that the federal government is better at local monitoring and oversight.

Of course, a highly diversified and decentralized approach to research allocation might not closely hew to dictates of popular political sentiment. That is precisely the point. Basic research should be freer and more open, permitting scientists to explore more broadly. This, after all, is the purpose of science.

In a university-centric distribution approach to funding decisions, university administrators who are on the front lines are far more able to judge not only the teams but also to ensure that proposed research falls within the innovation foundation zone of the Haroche-Schekman Continuum. Also, while not immune from the dictates of groupthink, a decentralized model would be far less susceptible to it. And, rather than adopting yet more legislation directing federal agencies to fund younger scientists,[106] the hundreds of recipient universities would, left to their devices, be far more likely to do so organically and reflectively.

To paraphrase an aphorism: science would be better served by guidance from the first two thousand names of the *American Men & Women in Science* biographical directory,[107] than by two hundred bureaucrats in Washington, D.C.

Incentivize Private Funding

The largest single source of R&D capital is found in the private sector. Eleven of the world's top 20 R&D spenders are in the United States; those 11 spend a total of $120 billion annually on R&D.[108] A further 14 million private American businesses engage in R&D, in one form or another, spending $260 billion.[109]

The federal government can unlock more private capital for basic R&D by: (i) accelerating and enhancing tax benefits for internal corporate R&D spent on basic science; and (ii) radically increasing tax deductions for any private organization, or citizen, funding university-based basic research. While there is the obvious risk that some will creatively "reclassify" projects that are actually "applied" as "basic" research, straightforward definitions can reasonably minimize such tax-driven reprogramming, ensuring that funds are dispersed as undirected general support for researchers rather than specific projects.

While Microsoft's $11 billion R&D budget, for example, includes some basic research, from quantum technology[110] to avian monitoring, far more could be supported by both newer and older corporate giants, whether, say, a Google or GM. Similarly, implementing tax preferences for private and corporate funding of basic research at universities could expand the trend toward philanthropic and corporate funding in the academy.[111]

De-Bureaucratize

The efficacy of all research dollars can be increased dramatically by cutting the bureaucratization of the application process for, and monitoring of, basic research. Current heavy-handed processes and oversight unproductively consume nearly half the money and time that could otherwise be spent doing research.[112] Modern "app-centric" and more open "trust-centric" administration are needed. Each university should be allowed to implement granting, operating, and oversight models that meet their own individual characteristics and scale. (It bears noting, too, that many university administrators are virtually institutionally paralyzed by preoccupation with risk avoidance and regulatory compliance issues that, while not specific to research, are damaging research itself.)

As a first step toward relieving the administrative burden, the federal government should expand its surveys of scientists to learn more specifically about broken processes and more user-friendly alternatives. For several decades, the Federal Demonstration Partnership, a cooperative initiative between ten agencies and 119 institutions receiving research grants, has been surveying the R&D community to unveil bureaucratic challenges. The partnership's work should be converted into an actionable process, transferring oversight authority to the field.

Finally, the central bureaucracy should adopt a twenty-first-century administrative tool kit. Grant applications must be made simpler, and monitoring should migrate from central reporting and policing to a neighborhood watch model. To create a software solution, run a broad contest attracting Silicon Valley–type software and app developers.

Stop the Slide

No one knows the perfect ratio for the share of GDP that should be allocated to R&D. We do know that the past half-century has seen the rise of American economic and technological dominance across industries and universities. Since we cannot know where future breakthroughs will originate, it is more sensible for government to fund research teams, not build industrial-scale projects (whether factories or power plants). Building teams is far cheaper, too.

More than adequate funds can be found to return to the historical share of GDP allocated to basic R&D—through modest reductions in government spending on applied research—thereby swinging the pendulum back from its current overemphasis on industrial-class development. Simply stated, encourage more federal funding of scientists and less of commercial businesses like Solyndra.

The NIH has a small, nascent initiative to fund "people, not projects," with "no strings" attached.[113] It is a good start that should be amplified. Private research institutions offer numerous examples of this latter approach, such as the successful Hughes Research Laboratories; universities, of course, instinctively prefer this model as well. Both should be encouraged to use federal funds to follow a talent-, people-centric research model. It is the pursuit of knowledge, by brilliant scientists, that unleashes revolutions.

CONCLUSION

The health of America's overall innovation ecosystem is, of course, influenced by many other important factors requiring sound government policy, including functioning capital markets, STEM education, rational tax policy, and intellectual property rights. This entire edifice nevertheless remains anchored in the advancement of scientists who produce new ideas and knowledge.

History suggests that a cure for cancer, or a miraculous new method to store electricity, or to store data, is more likely to be found by an unknown millennial, supported by a first-time grant, than from an established NSF or NIH "millionaire"—and, similarly, more likely to emerge from undirected research from unexpected areas, in big data analytics or nanochemistry, than from commercial projects better built by the private sector.

As for the tragedy of the commons, the likelihood is that U.S. basic research spending will diffuse to the broader benefit of foreign companies and nations. However, the nature of America's culture and capitalist model, as extensively documented by economics Nobelist Edmund Phelps,[114] gives the U.S. an inherent advantage in capturing the benefits of scientific advances.

In comparison with other core government responsibilities—notably defense, taxation, regulation, and jurisprudence—science policymaking is a new discipline. In the former, policymakers can draw on a rich history of trial and error, across many centuries, cultures, and political systems. This is not so for R&D. As a policy discipline, it is barely a half-century old. It's time to try something new.

Endnotes

[1] This paper does not evaluate the (noncivilian) Department of Defense R&D budget, which is 20 percent bigger than all civilian federal R&D budgets combined. Defense R&D is 97 percent focused on applications highly specific to unique military needs; however, the 3 percent allocated by the DOD to basic science has been historically valuable and continues to be so to this day.

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