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Paula Stephan*

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ABSTRACT

I examine and document how the Endless Frontier changed the research landscape at universities and how universities responded to the initiative. I show that the agencies it established and funded initially recruited research proposals from faculty and applications from students for fellowships and scholarships. By the 1960s the tables had begun to turn and universities had begun to push for more resources from the federal government for research, support for faculty salary and research assistants and higher indirect costs. The process transformed the relationship between universities and federal funders; it also transformed the relationship between universities and faculty. The university research system that has grown and evolved faces a number of challenges that threaten the health of universities and the research enterprise and have implications for discovery and innovation. Five are discussed in the closing section. They are (1) a proclivity on the part of faculty and funding agencies to be risk averse; (2) the tendency to produce more PhDs than the market for research positions demands; (3) a heavy concentration of research in the biomedical sciences; (4) a continued expansion on the part of universities that may place universities at increased financial risk and (5) a flat or declining amount of federal funds for research.

*Georgia State University and NBER. I have benefited from the comments of participants at the "Changing Frontier: Rethinking Science and Innovation Policy" Pre-Conference and Conference Workshops, especially those of the organizers Adam Jaffe, Benjamin Jones and Bruce Weinberg, the discussant. I have also benefited from discussions with Gregory Petsko and comments by Bill Amis. Various individuals helped in supplying unpublished data and answering inquiries. They include Robert Buhrman, Ronald Ehrenberg, John Griswold, Vicky Harden, Barbara Harkins, Peter Henderson, Richard Mandel, Joseph November, James Schuttinga, Buhm Soon, Lori Thurgood, and Hui Wang. Research assistance was provided by Nicholas Heaghney and Rhita Simorangkir.

1. Introduction

Science emerged from World War II triumphant. Its contributions to the war effort included the Manhattan project, radar, DDT, and penicillin. Its triumphs were sufficient to cause one National Institutes of Health scientist to remark that from the end of the War on, "science was spelled with a capital 'S' and research with a capital 'R'" (Strickland, 1989, p. 17).

The time was ripe for funding for scientific research to gain a firm national footing. No one understood this better, or was better positioned to promote it, than Vannevar Bush, President Roosevelt's Science Advisor and Director of the Office of Scientific Research and Development. Sensing that the moment was propitious for a public initiative, Bush maneuvered for Roosevelt to request a report laying out a federal course of action. The request was duly dispatched and in the late fall of 1944 Bush set about writing what was to bear the name: *Science the Endless Frontier*.

The report, issued in July of 1945, recommended a three-pronged course of action for the federal government.[1] First, the government should fund basic research at universities and medical schools, because these "institutions provide the environment which is most conducive to the creation of new scientific knowledge and least under pressure for immediate, tangible results" (Bush, 1945, p. 7). Second, the government should provide scholarships and fellowships to promote training. Both the research and training initiatives, it argued, were essential for economic growth; both addressed the concern that due in part to the War the United States faced a scientific deficit in terms of basic research and the highly trained individuals required to conduct the research. Third, the report recommended that the government continue to conduct research of a military nature during peacetime.

Science the Endless Frontier "established an intellectual architecture that helped define a set of public science institutions that were dramatically different from what came before yet largely remain in place today."[2] It also gave birth to and nurtured a university culture that, although initially a bit skeptical of federal support, quickly began to ask for more--not only from the federal government but also from faculty and staff. In the process, the research environment at universities underwent substantial change.

This paper sets out to examine how the *Endless Frontier* changed the research landscape at universities, the response of universities to the initiative, stresses that have emerged in the system and the implications they have for discovery and innovation. To cut to the chase: the *Endless Frontie*r set about to grow research capacity at universities and increase the supply of individuals qualified to do research. Initially the agencies it established were in missionary mode, recruiting research proposals from faculty and applications from students for fellowships and scholarships. By the 1960s, however, the tables had begun to turn and universities, having tasted federal fruit, aggressively began to push for more

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[1] Bush assembled a staff to assist in drafting the report. One of its members, Paul A. Samuelson, wrote an account of his role in the report in 2009 (Samuelson, 2009).

[2] Adam Jaffe and Benjamin Jones, email to possible participants of the NBER conference, "The Changing Frontier: Rethinking Science and Innovation Policy," April 5, 2012.

resources from the federal government, in terms of funds for research, support for faculty salary and indirect costs. Universities also began to demand more from faculty, in terms of external support for their research and support for graduate students. The process transformed the relationship between universities and federal funders; it also transformed the relationship between universities and faculty.

The plan of the paper is as follows: Section 2 describes the university research enterprise at the end of the war. Section 3 focuses on the early days at the National Institutes of Health (NIH) and the National Science Foundation (NSF). Section 4 examines the universities' response to federal funding during the 1960s. Section 5 focuses on the years 1970 until 2012. Section 6 takes stock of how the university research enterprise has evolved and changed since *The Endless Frontier.* Section 7 examines stresses to the system and ends with concluding thoughts.

2. The Scientific Landscape Circa 1940s and *The Endless Frontier*

Despite the large number of universities and colleges in the United States at the time Bush authored *Science the Endless Frontier*, only ten to fifteen could be considered top research universities.[3] The number of medical colleges doing research was even smaller. The typical medical school's faculty was largely composed of part-time clinicians with minimal interest in research.

Bush estimated that $31 million was spent on research at universities and medical schools in 1940 ($513 million in 2013 dollars—or less than one percent, in real terms, of what was spent on university R&D in 2012); almost all the funds came from endowments, private foundations and donations (Bush, 1945, p. 18). The small amount of university research supported by the federal government came by way of contracts. Grants as a mechanism for supporting research were rare.

Expenditures for research equipment and materials were modest by today's standards. The 200-inch reflecting telescope that Caltech was building at the time—later named the Hale--cost approximately $6 million dollars or $79 million in today's dollars. By comparison, the TMT that is currently on the drawing boards, a joint project of Caltech and the University of California, has an estimated price tag of $1 billion. The first model for Lawrence's cyclotron, built with wire and sealing wax, cost approximately $25, not enough in today's dollars to pay for a minute of the electricity required to run the Large Hadron Collider at CERN, estimated to have cost about $8 billion at the time it first came on line in 2008. Labs in chemistry and the biomedical sciences were reliant on table top equipment. Organisms used in research were often of the garden variety—worms, fruit flies and mice.

At the time of World War II, 47 institutions awarded the PhD degree in mathematics, 55 in physics, 74 in chemistry, 39 in earth sciences, 37 in engineering and 74 in the life sciences (Table 1). PhD production in science and engineering (S&E) had grown steadily during the 1930s, going from 895 in 1930 to 1379 in

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[3] Based on the number of doctoral degrees conferred in science and engineering, the ten-to-fifteen included the University of Chicago, Columbia, Cornell, The University of Wisconsin, Harvard, Johns Hopkins, the University of Illinois, University of California, Berkeley and Yale. Data provided by Lori Thurgood, unpublished.

1939 (Figure 1).[4] By 1940, the number of degrees awarded in S&E was 1618. As the war accelerated, however, the number of students enrolled in graduate school declined and PhD production in science and engineering fell to 1030 in 1944 and 743 in 1945 (Figure 1). A deficit clearly was in the making.

Table 1: Number of Doctorate Granting Institutions in the United States by 5-year Period 1929-1974

Field	1920-1924	1925-1929	1930-1934	1935-1939	1940-1944	1945-1949	1950-1954	1955-1959	1960-1964	1965-1969	1970-1974
Mathematics	22	33	43	45	47	49	71	74	91	127	159
Physics	28	37	46	55	55	54	74	84	114	150	167
Chemistry	43	47	66	76	74	84	100	112	143	171	194
Earth Sciences	24	24	37	39	39	38	50	59	74	96	121
Engineering	19	24	32	37	37	49	63	75	97	127	151
Life Sciences	42	57	65	70	74	81	99	122	144	178	224

Source, (National Academy of Sciences, 1978, p. 95)

Time spent in doctoral training was considerably shorter than time spent in training today. Although data are sparse, Bush estimated that it took about 6 years from high school to get a doctorate. Bush completed his own doctoral training in electrical engineering in two years.

The principle objectives of *Science the Endless Frontier* with regard to universities were to promote basic research through the provision of federal funds for research and to promote training of a future workforce by providing fellowships for doctoral and postdoctoral training, and scholarships for undergraduate students. When it came to research, Bush not only wanted to support research at established universities and medical schools but also wanted to build up less strong departments, especially at medical schools, which he saw as particularly lacking in terms of research capacity. With regard to training, while Bush advocated that training should occur in a research environment, he never suggested that the two should be jointly funded. Rather, he saw the two as separate activities.[5]

Bold for its time, the price tag was modest by today's standards. Bush envisioned that support for medical research would go from \$5 million a year to \$20 million a year in the fifth year "where it is expected that the operations have reached a fairly stable level" (\$65 million to \$260 million in 2013 dollars). With regard to the natural sciences, Bush saw funding going from \$10 million to \$50 million (\$130 million to \$650 million in 2013 dollars). Bush also saw stability of funding as key: "Whatever the extent of support may be, there must be stability of funds over a period of years so that long-range programs may be undertaken" (Bush, 1945).

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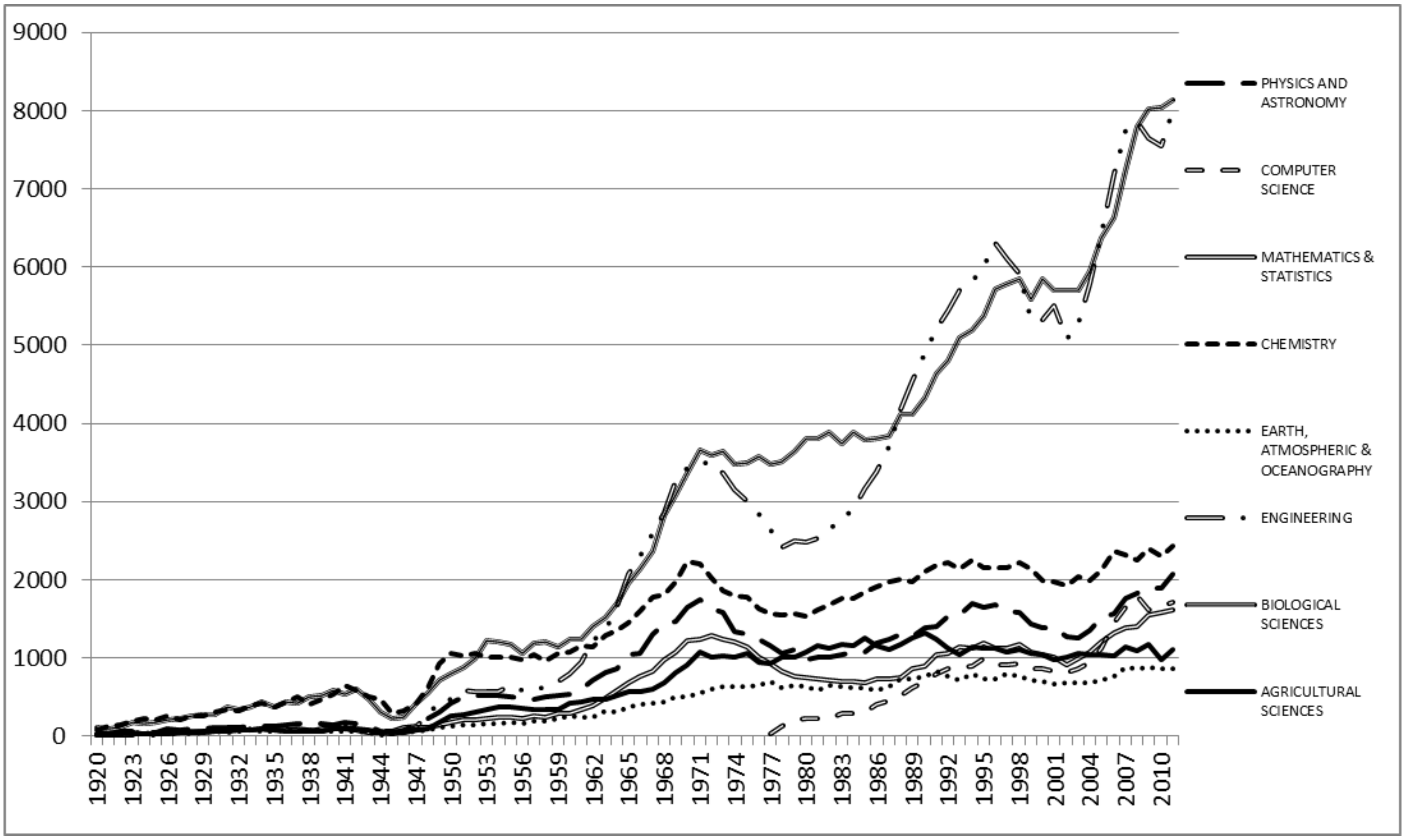
[4] Throughout this paper S&E is defined to include engineering, geosciences, life sciences, math and computer sciences, and the physical sciences.

[5] See discussion in (Teitelbaum, 2014).

Figure 1: PhD Production in Science and Engineering, 1920-2010



Source: Unpublished NSF records and NSF Webcaspar

The implementation of Science *The Endless Frontier* was largely the responsibility of two federal agencies: the National Institutes of Health (NIH), which had been formally established in 1930, and a new federal organization for research, referred to in the report as the National Research Foundation in the report.[6] Providing funds to the firmly established NIH proved much easier than establishing the new agency that Bush envisioned and the NIH clearly benefited from the political hurdles faced in creating the former.[7] It was not until 1952 that the National Science Foundation opened for business.

3. Early Years of the NIH and the NSF

3.1 NIH

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[6] Health research became more consolidated in 1944 when the National Cancer Institute, established in 1937, was incorporated into NIH.

[7] A primary opponent of Bush's plan was Senator Kilgore of West Virginia whose proposal to create a national science foundation, first introduced in 1942, had, as one of its objectives, the "geographic" distribution of the funds. It took five years to work out a compromise, which included among other things the provision that the new agency was to avoid an "undue concentration" of its funds. Finally, in 1952, the National Science Foundation became operative. See http://www.nsf.gov/pubs/stis1994/nsf8816/nsf8816.txt.

The NIH's budget in 1948 of $25 million was reasonably consistent with what Bush had envisioned for health-related research. However, by 1950, in nominal terms, the budget had almost doubled to $48 million. It doubled again by 1956; and again by 1958 and still again between 1958 and 1960, where it stood at approximate $400 million ($3.1 billion in 2013 dollars). Clearly Bush had underestimated the amount of funds that would be directed to health research (National Institutes of Health).

In its early years, NIH was in missionary mode, encouraging institutions and individuals to submit proposals. To quote Fred Stone, circa 1950, an NIH official who later became the director of the National Institute of General Medical Science (NIGMS) , "It wasn't anything to travel 200,000 miles a year" (Strickland, 1989, p. 38). This was consistent with NIH's view of its mission, which was not only to support top research but to build programs. NIH also built capacity by supporting the construction of facilities at universities.

Grants were initially reviewed by sending them out to eminent scientists (National Institutes of Health, circa 1959). But by 1946 the concept of study sections had evolved, and henceforth, peer review was to be organized around these. Success rates were high, by all account 65 percent or more (Divison of Research Grants, 1996). Requests were reasonably modest. The average grant, which was approximately $9,000 ($87,000 in 2013 dollars), lasted approximately a year (Munger, 1960). This quickly changed. By 1951 the average duration of a grant was 1.8 years; by 1955 it was 2.5 years and by 1957 it was 3.2 years (Munger, 1960, p. 20).

In its early years NIH adopted the policy that the renewal award documents show the number of years of previous support for a particular project, a "high number portending a long-term commitment" (Appel, 2000, p. 211). Not surprisingly, success rates for renewals were even higher and investigators became reluctant to change research focus.

Indirect rates were low: 8 percent. As early as 1951 various university and medical associations asked that it be raised to 15 percent. The request was refused (Divison of Research Grants, 1996, p. 59). In 1956, however, the rate was raised to 15 percent; it was raised again to 25 percent in 1958 (Munger p. 32). Although the goal was for grants "to add rather than replace support from the parent institution" (History of Extramural Research and Training Programs at NIH, mimeo, circa 1959), at some point in its early years, if requested, NIH began to pay for a portion of faculty salary on the grants. Indeed, one reason that individuals reportedly preferred NIH grants over NSF grants in the early years was precisely for the ability to write off salary at NIH (Appel, 2000). While NIH's extramural grants program focused on individual research projects, it also included funding for facilities and for equipment (Strickland, 1989, p. 72).[8]

Grants were heavily concentrated in the early years at a handful of institutions. Columbia University headed the list, receiving more than 5 percent of the funds, followed by Johns Hopkins, New York University, Harvard and the University of Minnesota (Appendix, Table A1) Taken together, the top ten institutions in 1948 received slightly more than one-third of all the NIH award funds; the top fifty

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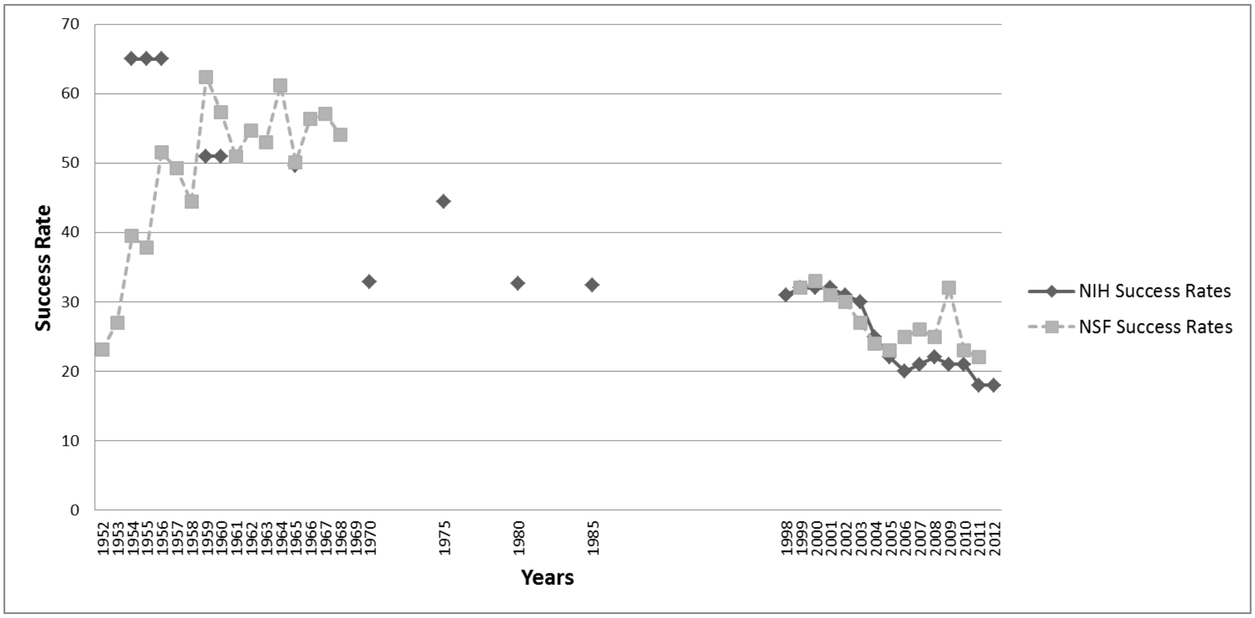
[8] See (November, 2012) for a discussion of the conscious and directed effort on the part of NIH in the 1950s and early 1960s to computerize the fields of biology and medicine.

received approximately 75 percent. Despite the heavy concentration, approximately 120 universities, medical schools, and colleges received one or more of the 795 research grants that institutions and hospitals were awarded that year.[9]

Outreach was met with increased demand. The number of research projects reviewed by study sections almost tripled in the 1950s, going from 2750 to 7975 (Divison of Research Grants, 1996, p. 70). The average request also increased, going from $12,500 to $19,500 in today's dollars (Divison of Research Grants, 1996, p. 70). Approval rates fell in the 1950s from 65 percent to the low 50's (Figure 2). It was not solely a question of the availability of funds. It was also a strategic decision to signal to Congress and the President that NIH only funded quality research (Divison of Research Grants, 1996, p. 81).

Figure 2: NIH and NSF Success Rates, Available Years



Source: NSF Rates for 1952-1968 are for the Division of Biological and Medical Sciences; those for 1999 and thereafter are for all of NSF. Source: (Appel, 2000, p. 70) and various Reports to the National Science Board on the NSF's Merit Review Process, various fiscal years. Data for NIH rates are from (Chubin, 1990, p. 26) and NIH data book http://report.nih.gov/NIHDatabook/Charts/Default.aspx?showm=Y&chartId=124&catId=13;

NIH saw the shortage of talent to be a major bottleneck in getting the research done. According to Mary G. Munger, writing in 1960 on the history of the first 12 years of NIH, "from the beginning of the extramural research grants programs, the lack of a sufficient number of qualified research investigators was a continuing bottleneck" (Munger, 1960). To promote training, NIH awarded predoctoral and postdoctoral fellowships, selecting applicants in house. However, it rapidly shifted some of the

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[9] A document dated 1948 lists names and amounts for the 198 institutions that received Public Health Service Grants in Aid in 1948. At least 79 of these were independent research organizations, hospitals or, in a few cases, foreign institutions. See http://history.nih.gov/research/downloads/PHSResearchGrantsinAID-June30th1948.pdf

responsibility for selection to institutions, with the creation of training grants awarded to institutions to train individuals that they selected. Stipends started at $1800 ($19,250 in 2013 dollars) for a first-year predoctoral fellowship and $4500 ($48,000 in 2013 dollars) for first year postdoctoral fellowships; most recipients of the latter in the early years were medical doctors. Allowances were also provided for dependents, travel and tuition (National Institutes of Health, circa 1959, p. 12). When concern was raised in 1948 that "NIH fellows were being used simply as research assistants, as extra pairs of hands, as cheap labor" NIH changed and strengthened the criteria for fellowships, trying to ensure that the fellow not "remain a sidekick to a senior scientist for an indefinite length of time"(Strickland, 1989, p. 45).

3.2 NSF

NSF's initial budget for 1952 was meager compared to that of NIH's, starting at $3.5 million ($30.5 million in 2013 dollars). It grew rapidly, however, during the 1950s and by 1960 total obligations for NSF were $158.6 million ($1.2 billion in 2013 dollars) or approximately 40 percent the size of NIH's budget at the time (Appel, 2000, p. 69).[10] Although committed to quality, NSF, like NIH, made an effort to identify "atypically good researchers in underdeveloped institutions" (Appel, 2000, p. 59).

Like NIH, NSF also awarded funds in the form of grants to assist faculty in doing research rather than award contracts for the purchase of research. Grants were reviewed and scored on a five-point scale by panels, populated through the "old boys network" (Appel, 2000). In the early days, it was even possible to be a member of a review panel and have one's own research proposal reviewed and funded. Although success rates were initially below 30 percent, reflecting pent-up demand, by the mid-1950s success rates had grown, with but one exception, to over 50 percent (Figure 2). In 1959 the success rate was 62 percent (Appel, 2000, p. 70).[11] Renewals (although NSF, unlike NIH, did not formally refer to them as such) had significantly higher success rates, always over 80 percent. Requests were generally for modest amounts. The median award in 1952 was $9,000 ($78,000 in 2013 dollars--identical to that at NIH in the late 1940s); the average grant lasted for two years, however, instead of one. By the late 1950s the duration of grants had lengthened, especially for strong investigators, who often received funding for three to five years. The size of the grant also increased. Leading researchers could count on $20,000 a year, and in some instances as much as $30,000 a year ($159,000 to $237,000 in 2013 dollars) (Appel, 2000, p. 77).

Indirect rates were initially set at 15 percent but were raised to 20-25 percent by the mid-1950s (Appel, 2000). From its beginnings, NSF willingly supported two months of summer salary but resisted supporting academic-year salaries; NSF leadership saw this as the responsibility of the university. Despite the opposition, in some instances support for academic-year salary was provided. Moreover, facile administrators and scientists could move money from one budget category to another after the

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[10] This figure overstates the disparity between the two for support of university research because a goodly portion of NIH funds supported intramural research programs while NSF did not have an intramural research program.
[11] Success rates are for the division of Biological and Medical Sciences (Appel, 2000, p. 70).

award had been made (Appel, 2000). NSF also provided funds for the purchase of large instruments, supplies, travel, publication, educational projects, technicians and facilities.

In its first year of operation, NSF awarded 98 grants totaling $1.1 million ($9.5 million 2013 dollars); 60 colleges and universities were recipients. The largest amount of funding was awarded to Caltech (6.9 percent), followed by Indiana University, Bloomington (5.2 percent). The number of academic institutions receiving grants grew by 25 percent the next year; the number of awards increased to 172, and funding increased to $1.7 million ($14.5 million in 2013 dollars). The largest amount of funding went to Harvard University (6.5 percent), followed by Yale (6.3 percent). Taken together, the top ten institutions received 42 percent of the award funds (Table A.2).

Consistent with Bush's vision and mission to build capacity, the Division of Scientific Personnel and Education was established within NSF as part of the initial NSF Act to award fellowships to students for graduate training. The selection process was overseen by the National Research Council. In the early years, the division awarded between 500 and 600 fellowships a year. The original stipend was for $1600 ($13,900 in 2013 dollars), plus tuition and fees. The fellowship was usually awarded for three years (Freeman, Chang, & Chiang, 2005). The division also awarded fellowships for postdoctoral training. From the beginning, graduate students and postdoctoral students were also supported on faculty grants. An audit of grants awarded by the division of Biological and Medical Sciences (BMS) in 1956 showed that 75 percent of one unit's awards supported predoctoral students; 20 percent of the units awards included salaries for postdoctoral fellows (Appel, 2000, p. 79).

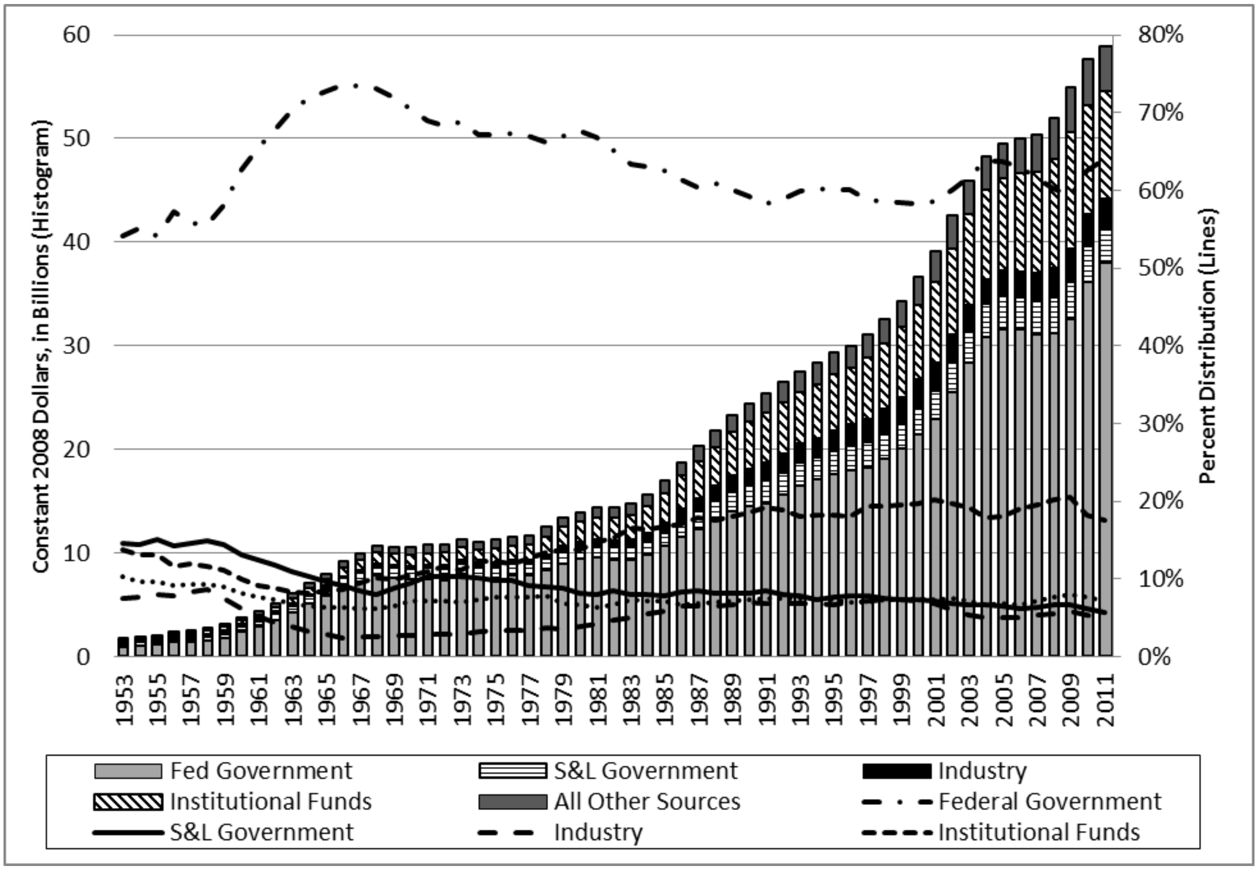
3.3 Other federal sources, Sputnik and the NDEA

Data are sparse to document in any detail the amount of research funds that came to universities from other federal agencies during the late 1940s and 1950s. Clearly, however, agencies other than NIH and NSF supported university research. Key among these was the Department of Defense (DOD,) whose budget for research grew dramatically during the Cold War. DOD funding, unlike that of NSF and NIH, was highly concentrated at a handful of institutions. At the top was MIT, which in the late 1940s had 75 separate contracts for defense-related work, totaling $117 million (Leslie, p. 14-15). Caltech was next with $83 million in contracts; Harvard a far third with $31 million. (Assuming that these figures are for 1947, this represents, respectively, $1.25 billion, $888 million and $331 million in 2013 dollars.) Throughout the Cold War, MIT maintained its dominant position, receiving more in contracts than many large industrial defense contractors. Unlike the NIH and NSF model, however, whose funds went primarily to individual investigators, DOD funds were directed to interdisciplinary research labs at universities. It is also notable that funds came in the form of contracts, not grants. Other universities learned from MIT's experience and used postwar defense contracts to propel themselves into research-university status. Stanford was an early example; more recently the Georgia Institute of Technology and Carnegie Mellon have benefited from defense-related research ((Leslie, 1993, p. 12) and (Stephan & Ehrenberg, 2007, p. 4)).

In 1957 the Soviet Union launched Sputnik. The U.S. responded in part by dramatically increasing federal support for university research, which nearly quadrupled during the period 1958-1968, going from

$2720 million in constant 2008 dollars to $10,685 million (Figure 3). Universities also benefited from the scholarships and fellowships for students that the federal government provided post-Sputnik through the National Defense Education Act (NDEA). Retrospectively, the 1960s would be seen as the "golden age" of university research.

Figure 3: Support for Academic R&D by Sector: 1953-2011



Source: NSF Webcaspar

4. The University Response to Capacity Building: The 1960s

Universities were extremely responsive to the capacity-building initiatives of NSF and NIH, increasing the number of PhDs they trained and the number of grants they submitted. But while the 1950s can be seen as a period where the federal government took the initiative in building the capacity of universities to do research, the 1960s can be seen as a transition period in which the tables began to turn. Universities not only responded to the government's capacity building initiative; they began to aggressively push the government to cover salaries on grants and raise the allowable indirect rate. In short, before the 1960s, the federal government was pushing universities to develop research-and-training capacity and to perform research. After that, the roles were reversed and universities began to push the federal government for funds. Positive feedbacks of the system had begun to emerge, feedbacks that Vannavar Bush had not foreseen.

A number of metrics show the success with which capacity was built during the 1950s and 1960s. For example, the number of PhD recipients awarded in 1959 was 250 percent higher than its pre-war high (Figure 1). It was not just that traditional pre-war programs were educating more PhDs but that new programs were being created. Between the early 1950s and the early 1960s, the number of PhD programs increased by over 40 percent in all fields save math (Table 1). Strong federal funding for students and research provided incentives for PhD production to continue to grow in the 1960s, tripling during the decade. Once again, it was not only that there were more PhDs. There were more programs. By the end of the decade, 27 percent of PhDs were being awarded by the top ten-PhD granting institutions in science and engineering, compared to 68 percent four decades earlier. American higher education was becoming more democratized (Table 2).

The growth in PhD production was due in large part to the dramatic increase in federal support for PhD study after the War. The expansion, particularly in the late 1960s and early 1970s, was also encouraged by the availability of draft deferments for graduate study until 1968. In the short period between 1966 and 1970 the number of science and engineering doctoral degrees awarded per thousand 30-year olds in the U.S. population increased by almost 50 percent, going from 9 to 13 (National Science Foundation, 1994, p. 26).

Table 2: Top 25 Universities Awarding PhDs in Science and Engineering, 1920-1924, 1968, 2011

Name of Institution 1920-1924	Number of PhDs 1920-1924	Name of Institution 1968	Number of PhDs 1968	Name of Institution 2011	Number of PhDs 2011
University of Chicago	347	U. of Illinois at Urbana-Champaign	409	Stanford University	512
Columbia University in City of NY	264	U. of California-Berkeley	391	University of California-Berkeley	510
University of Wisconsin-Madison	215	U. of Wisconsin-Madison	382	Massachusetts Institute of Technology	504
Cornell University	207	Purdue University	300	University of Florida	503
John Hopkins University	186	Massachusetts Institute of Technology	292	University of Illinois at Urbana-Champaign	494
Harvard University	152	U. of Michigan - Ann Arbor	282	University of Michigan - Ann Arbor	487
U. of Illinois at Urbana-Champaign	144	Stanford University	274	Purdue University	472
University of California-Berkeley	132	Cornell University	270	University of Wisconsin - Madison	470
Yale University	125	University of Minnesota-Twin Cities	241	Pennsylvania State U., Main Campus	436
U. of Minnesota-Twin Cities	83	Ohio State University	206	University of Washington-Seattle	426
Ohio State University-Columbus	80	University of Texas at Austin	204	University of Minnesota-Twin Cities	417
U. of Michigan-Ann Arbor	80	Iowa State University	201	Georgia Institute of Technology	407
U. of Iowa	79	Michigan State University	198	Ohio State University	398
U. of Pennsylvania	71	University of California-Los Angeles	187	University of California-Los Angeles	377
Princeton University	65	Harvard University	186	University of California-Davis	376
Massachusetts Institute of Technology	56	University of Washington-Seattle	156	Texas A&M University Main Campus	373
Stanford University	41	Columbia University in the City of New York	155	University of California-San Diego	344

George Washington University	36	Case Western Reserve University	151	Cornell University	339
Clark University	33	U. of Maryland at College Park	146	University of Texas at Austin	328
New York University	29	Pennsylvania State University	143	University of Maryland at College Park	325
U. of Pittsburgh-Pittsburgh	26	John Hopkins University	140	John Hopkins University	317
Iowa State University	23	Northwestern University	138	University of North Carolina at Chapel Hill	302
Washington University-MO	21	University of Pennsylvania	136	North Carolina State University at Raleigh	300
Indiana University- Bloomington	20	Texas A&M University	135	Columbia University in the City of New York	297
Rutgers St UNJ-New Brunswick	20	New York University	131	Virginia Polytechnic Institute and State University	288
Total top 10	1855		3047		4814
Percent	68.1		27.1		17.12
Total top 25	2535		5454		10002
Percent	93.1		48.63		35.67
Total PhDs in S&E Awarded	2724		11215		28042
Total Number of institutions awarding a PhD in S&E	55		194		326
HHI	426		139		83

Source: 1920-1924 data, Lori Thurgood, correspondence of unpublished tabulations; 1968 and 2011 NSF Webcaspar.

The federal government played virtually no role in the support of PhD students prior to WWII. During the 1950s, however, the federal government began to play a major role through the provision of fellowships by NSF and NIH and also through the support of training programs. Moreover, a new use of federal research funds began to emerge in the 1950s—support of a graduate research assistant--on a faculty member's grant. By 1961, for example, research grants in BMS at NSF supported 985 predoctoral students, 27 percent of all PhD degrees awarded in the bio sciences in the years 1959, 1960 and 1961 (Appel, 2000, p. 92). Across all NSF directorates, in 1966, a year for which data are readily available, NSF supported almost 11,000 graduate students: 23.4 percent on fellowships, 35.9 percent on traineeships and 34.6 percent as research assistants on faculty grants (National Science Board, 1969). The same year NIH supported almost 10,000 graduate students—25.7 percent on fellowships, 47 percent on training grants and 25.6 percent as research assistants.[12]

Other federal agencies also supported graduate students. The Atomic Energy Commission supported a substantial number of research assistants and NASA had a large training grant program. In addition, "other" federal agencies supported approximately 10,600 graduate students in 1966, the majority of whom (63 percent) were as research assistants (National Science Board, 1969).

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[12] The importance of training grants and fellowships increased during the decade. By 1969, NIH reported supporting 9,500 students in such positions. The 1969 number represents the peak of NIH support for students in the form of fellowships and training grants. By the end of the 1970s, NIH was supporting fewer than 5,000 a year on training grants and fellowships.

The federal government also built capacity by supporting postdoctoral fellows. Although the concept of postdoctoral study dates to 1919 (Assmus, 1993) support for postdoctoral study before the war was minimal and the support that did exist was largely provided by private foundations such as Rockefeller. From the very beginning, however, NIH saw postdoctoral study as a major way to build research capacity. Throughout the 1950s and 1960s the number of postdocs supported on training grants grew, as did the number supported on fellowships. While some of these postdoctoral positions were for study at NIH, many were for postdoctoral study at a university or medical school. Although data are sparse, the inference can be made that in 1969 NIH was supporting about 6,050 individuals on postdoctoral fellowships and training grants.[13] NIH supported additional postdocs on faculty research grants, although the number cannot readily be determined. NSF also allowed faculty to pay the salaries of postdocs off research grants. BMS in 1961, for example, supported 213 postdocs on research grants, approximately 9 percent of the PhDs awarded in biology during the two preceding years (Appel, 2000, p. 92).

The support of research assistants and postdocs on federal research grants meant that the government was now supporting graduate students and postdocs in order to get the research done now and not only supporting graduate students and postdocs on fellowships and training grants to build future research capacity. Perhaps because of this new role, the median time individuals spent in a PhD program (measured as "registered time") grew slightly, going from 4.9 in the physical sciences and 5.0 in the life sciences to 5.1 and 5.3 respectively between 1958 and 1963 (Table 3).[14] If Vannavar Bush's two-year degree is even remotely representative, time to degree had grown considerably since he received his degree in 1917. The observation is consistent with finding that individuals supported on training grants and fellowships completed graduate training 1-2 years earlier than those not supported on these grants (Coggeshall & Brown, 1984). It is also consistent (see below) with a view expressed in the Seaborg report.

Increased capacity meant greater demand for research grants as newly-minted PhDs came of professional age and joined their elders in submitting grants. By way of example, the number of proposals received by BMS at NSF grew from approximately 300 in 1952 to 2462 by 1968 (Appel, 2000, p. 70). The number of competing research project applications at NIH went from 2750 in 1956 to 7975 in 1960 (Divison of Research Grants, 1996). Not surprisingly, success rates began to decline (Figure 2). The increase in submissions continued to grow. In 1987, for example, the Division of Research Grants at NIH received 33,804 proposals (Strickland, 1989, p. 86). The number of institutions supported by NIH grew as well, going from 120 in 1948 to 330 in 1971 (Figure 3). At NSF, the figure went from 75 in 1953 to 314 in 1971. Grants became less concentrated as measured by the percent of funds that the top 10 institutions received, going from 42 percent in 1953 to the low 30s in the early 1970s at NSF (Figure A.1). At NIH it went from 36.3 percent in 1948 to the mid-20s (Figure A.2). DOD funds, which were highly concentrated among just three institutions in the late 1940s, were more evenly spread by 1971 (Figure

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[13] Estimate based on the assumption that 37.9 percent of the individuals supported were postdocs, basing this proportion on data for 1992 (National Research Council, 1994, p. 97).

[14] Table 1-3 (National Science Board, 1969).

A.3). The top 10 institutions received 41.7 percent of the research funds; overall, 244 institutions received DOD contracts or grants (Figure 4).

By the early 1960s, universities, nurtured by the federal government in the 1950s, had begun to depend upon federal support and to press for more. The 1960 report of the President's Scientific Advisory Committee (PSAC), *Scientific Progress, the Universities, and the Federal Government,* often referred to as the Seaborg report after its chairman, Glenn T. Seaborg, made the case for increased federal support on a variety of fronts (The President's Scientific Advisory Committee, 1960).[15] Included were federal support for salaries of new hires (allowing universities to make long term commitments), increased indirect rates on grants and additional funds for university research so that the nation could double its fifteen to twenty "centers of excellence" to 30 or 40 in fifteen years. The report also pressed for more fellowships for graduate study in science, recommending fellowships over research assistantships or teaching assistantships, which it saw as legitimate part-time work but cautioned that "these instruments are not without hazard: it is possible to do much harm to a young scientist, either by subordinating his need for a lively research experience to the requirements of a large organization or by exploiting his first enthusiasm for teaching by assignment exclusively to routine pedagogical tasks" (The President's Scientific Advisory Committee, 1960, p. 17). It also expressed the concern that increased time to degree reflected the practice of taking part-time positions while training.

Table 3: Registered Time to PhD Degree, Selected Years

Year	Physical Sciences	Engineering	Life Sciences
1958-1960	4.9	5.0	5.0
1963	5.1	5.1	5.3
1968	5.1	5.1	5.3
1973	5.7	5.6	5.5
1978	5.9	5.8	5.9
1983	6.1	5.9	6.2
1988	6.3	6.0	6.6
1993	6.7	6.5	7.0
1998	6.7	6.7	7.0
2003	6.8	6.9	6.9
2008	6.7	6.7	6.9

Source: Survey of Earned Doctorates. NSF/NIH/USED/USDA/NEH/NASA Survey of Earned Doctorates, updated data. Source for 1958-1960 (National Science Board, 1969, p. 24)

The request for across the board salary support went nowhere. The Seaborg report, however, met with some success when it came to indirect rates and funds for centers of excellence. In 1966, for example, NSF announced a policy of negotiating the overhead rate university by university (Appel, 2000, p. 161). In 1964 NSF created the Science Development Program with the goal of creating additional "centers of excellence." Later in the decade, it changed its goal to providing support to programs that already showed some existing strengths (Appel, 2000, p. 174). Other agencies also supported "upgrading"

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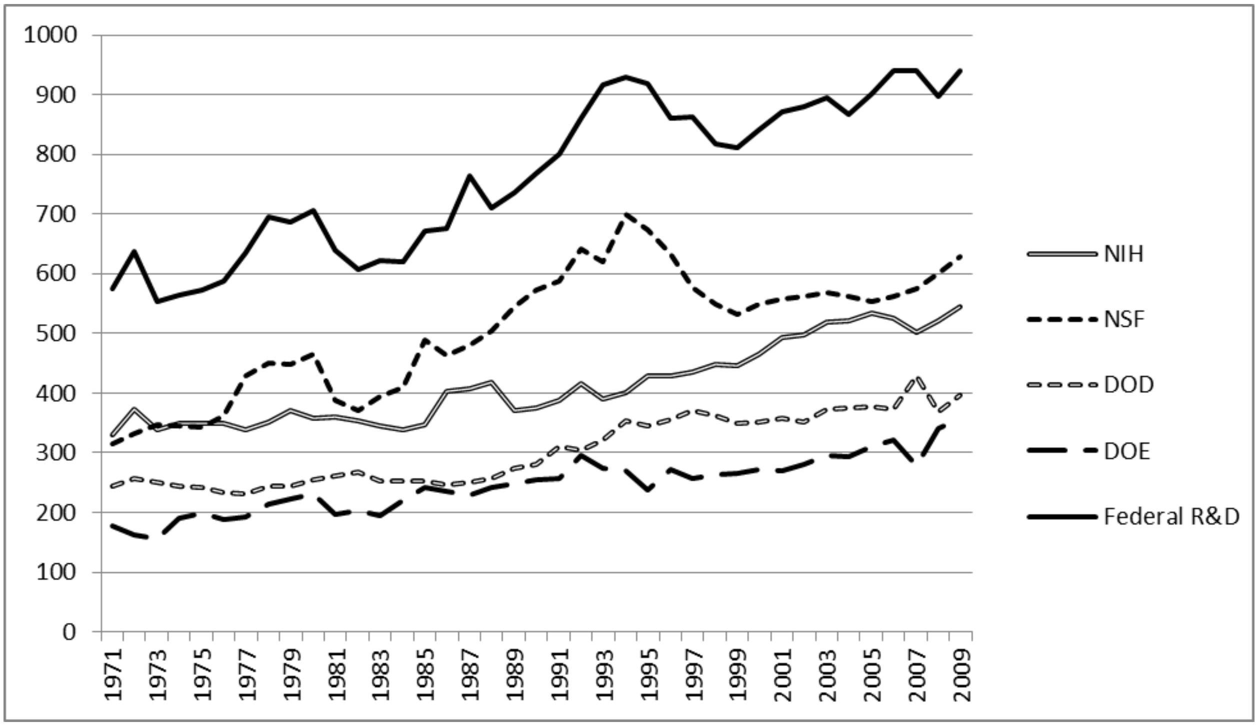
[15] Available at http://babel.hathitrust.org/cgi/pt?id=pur1.32754081232229;page=root;view=image;size=100;seq=1. Last accessed June 25, 2013.

initiatives. The Department of Defense, for example, had project THEMIS, NASA created the Sustaining University Program, and NIH created Health Science Advancement Awards (Appel, 2000, p. 175).

Figure 4: Number of Universities Receiving Research Funds, Various Federal Agencies, 1971-2010



Source: NSF Webcaspar

Although government agencies resisted providing long-term funds to universities in support of salaries, federal agencies became increasingly sympathetic to the request that grants cover academic-year salary for the time faculty spent on funded research.[16] As early as 1960, NSF yielded to the demand of college administrators to cover salaries, allowing faculty to charge off academic-year faculty salaries as a direct cost on grants (Appel, 2000, p. 161). By the end of the 1960s, NIH regularly paid salaries of tenured faculty (Appel, 2000, p. 333). Indeed, in 1968-69 almost half the medical school faculty in the country received some salary support from the federal government. The salary argument was given ballast by the fact that mission agencies, such as the Army, and the Air Force, were willing to pay up to 100 percent of faculty salaries (Appel, 2000, p. 161).

Faculty were not uniformly supportive of the push to put salaries on grants. The PSAC report noted the concern, stating that "We recognize that many university scientists are strongly opposed to the use of federal funds for senior faculty salaries. Obviously we do not share their belief, but we do agree with them on one important point—the need for avoiding situations in which a professor becomes partly or

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[16] The press for salary coverage was made not only by PSAC, but also by an earlier report of the Committee on Sponsored Research of the American Council on Education.

wholly responsible for raising his own salary."[17] It went on to say "If a university makes permanent professorial appointments in reliance upon particular federal project support, and rejects any residual responsibility for financing the appointment if federal funds should fail, a most unsatisfactory sort of "second-class citizenry" is created, and we are firmly against this sort of thing" (The President's Scientific Advisory Committee, 1960, p. 24).[18]

The Seaborg report also met with some success with regard to increased federal support for fellowships, especially from NSF and NIH. The NIH increase has been noted above. But NSF also provided more fellowships: between the mid-1960s and the late-1960s, the number of fellowships it awarded rose by approximately two-thirds (Freeman, Chang, & Chiang, 2005, p. 33).

One cannot leave a discussion of university science in the 1960s without noting that the 1960s is arguably a period in science in which, to use Steven Weinberg's terminology, "the logic of discovery" changed, especially in the physical sciences, forcing several disciplines to become big. In physics, the Berkeley Bevatron, which had become operational in 1954, rapidly became obsolete: "to make sense of what was being discovered, a new generation of higher-energy accelerators would be needed" (Weinberg, 2012). The new accelerators would be too large for one laboratory and increasingly the new facilities that were required were too big for one institution, or one country. National and international laboratories such as Fermilab and CERN became important. The same logic was leading astronomers to request larger and larger instruments.

The logic of discovery was to transform the biomedical sciences, as well--but several decades later--with the invention of "designer" mice (Murray, 2010) and the ability to automate the sequencing of genomes (Stephan, 2012). Much of the equipment associated with these shifts in logic, although expensive, was still affordable at the lab or institutional level. Some, however, such as an NMR, carried sufficiently large price tags to encourage, if not demand, collaboration across institutions.

5. The 1970s-2012

5.1: The 1970s

University administrators associated with the Seaborg report acknowledged that universities would be in a difficult position if the federal government were to back away from its support for research. But they dismissed the possibility (Beadle, 1960, p. 13). Yet only eight years after the report had been issued, universities were to find themselves in a precarious position when the brakes were put on and federal funding for research remained virtually flat in real terms for almost a decade (Figure 3). Indeed, between 1968 and 1972, real federal expenditures for university R&D declined by 6 percent. Over the

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[17] Alan T. Waterman, the first director of NSF, shared this concern, recognizing "that salary support led to such undesirable consequences as university pressure on faculty to cover their salaries through grants" (Appel, 2000, p. 161).

[18] The PSAC report also expressed the concern that paying for salary on grants could lead to the redistribution of income. Some university and federal administrators also expressed the concern that federal support for faculty salaries and research was leading faculty to become more loyal to Washington than to their home institution.

longer period, between 1968 and 1978, they increased by only 5 percent, in stark contrast to the five-fold increase between 1958 and 1968. The "golden age" of university science had ended.[19]

University research was sustained during this period in large part because funding from other sectors grew. A major source of growth came from institutions themselves, whose self-contributions to research increased by 55 percent, and by contributions from all other sources ("other"), which includes philanthropic organizations, that grew by 68 percent. Industry's expenditures on academic research increased by almost 70 percent; that from state and local governments grew as well, but by a modest 30 percent.

The cut in federal programs was reflected in federal support for fellowships. The number awarded for graduate study by NSF was halved (Freeman, Chang, & Chiang, 2005); the number of training positions that NIH supported at the predoctoral and postdoctoral level fell by almost one-quarter.[20] Not surprisingly, PhD enrollments declined,[21] and by 1972 the number of PhDs awarded had begun to decline; PhD production was not to catch up with the 1971 high of almost 14,000 until 1987 (Figure 1). Particularly hard hit were the fields of physics (60 percent decline), mathematics (33 percent decline) and chemistry (30 percent decline). The fields of engineering and biology experienced modest declines at most. Time to degree increased by 0.6 to 0.8 years depending upon broad field, reflecting, perhaps, the shift from training grants and fellowships to graduate research assistantships (Table 3). Despite the decrease in PhD production, the number of institutions awarding the PhD in science and engineering continued to increase, growing in most fields by 25 percent between 1965-1969 and 1970-1974 (Table 1). The increase in PhD programs was fueled in part by newly emerging universities which, in a buyer's market, were able to hire well-trained PhDs, who, in turn lobbied for and often got new PhD programs—another indication of the positive feedbacks in the system that Bush had not foreseen.

Competition for contracts and grants intensified. Success rates at NIH, which had plummeted during the 1960s increased in the mid-1970s only to fall again by the end of the decade (Figure 2). The concentration of NIH grants remained virtually unchanged. The HHI measure of concentration for the period, for example, varied by at most 5 percent (Figure 5).[22] The share of funds received by the top ten institutions remained constant, with but one exception, throughout the decade at around 27 percent

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[19] The War in Viet Nam was a factor in the federal government putting on the brakes for university research as was the Mansfield Amendment of 1969. Declining tensions with the Soviet Union also led the DOD to award less funding to universities for research.

[20] NIH supported 16,000 training grants in 1969. In the early 1970s, when the Nixon administration tried to eliminate the award, Congress responded with the National Research Service Award (NRSA) Act of 1974, providing funds for training in areas where "there is a need for personnel." In 1976, 11,500 trainees received support (National Research Council, 1994, p. 93).

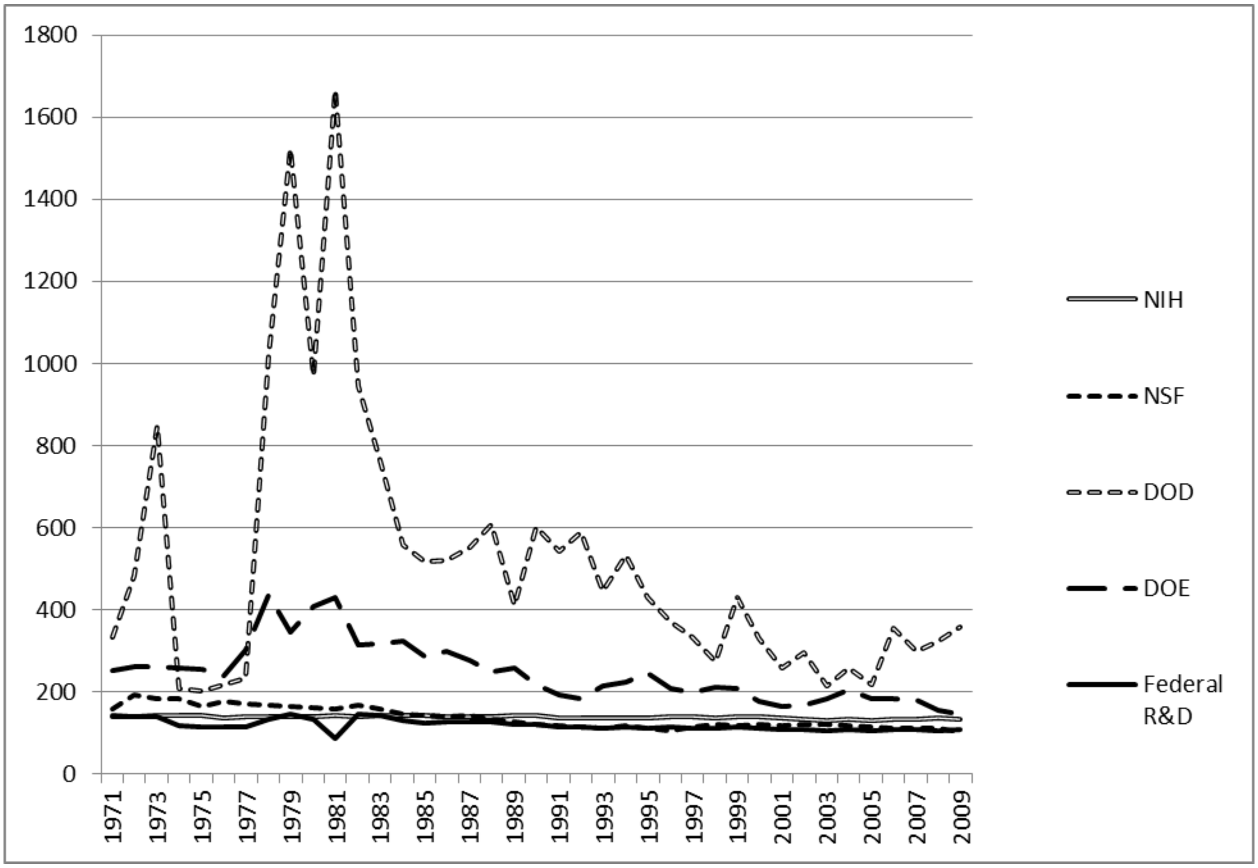
[21] The decline in PhD enrollments reflected also poor market conditions for scientists and engineers in the late 1960s and early 1970s and the abrupt halt to draft deferments for graduate study (Levin & Stephan, 1992).

[22] The Herfindahl–Hirschman Index (HHI), a commonly accepted measure of concentration, is calculated by squaring the share of each university and then summing the resulting numbers. The Department of Justice considers a share between 1,500 and 2,500 points to be moderately concentrated, and considers markets in which the HHI is in excess of 2,500 points to be highly concentrated. http://www.justice.gov/atr/public/guidelines/hhi.html

(Figure A.2). The number of universities and medical schools receiving funding stayed almost constant as well, just shy of 350 (Figure 4).

Things played out somewhat differently at NSF, where the number of institutions receiving grants grew considerably, especially during the late 1970s (Figure 4). Resources became less concentrated, as well (Figure A.1). The HHI index, which initially increased, fell by more than 10 percent; the top ten institutions saw their share decrease from 35 percent in 1972 to almost 30 percent in 1980. At DOD, funds were considerably more concentrated, and patterns were considerably more sporadic, reflecting both "lumpy" contracts and stop-and-go funding (Figure A.3). Even in the most equal of times, funds at DOD, as measured by the HHI index, were considerably more concentrated than at the other federal agencies (Figure 5). The share that the top ten institutions received stayed above 35 percent throughout the period and at times exceeded 60 percent. DOE was yet a different story. Although the number of universities receiving funds increased during the latter 1970s, DOE funded fewer universities than did the other three agencies (Figure 4). Moreover, funds were slightly more concentrated than at NSF or NIH and during the end of the 1970s the degree of concentration increased, as measured by the HHI index (Figure 5). See also Figure A.4)

Figure 5: HHI Index of Concentration, NIH, NSF, DOE, DOD, All Federal Funds, 1971-2009

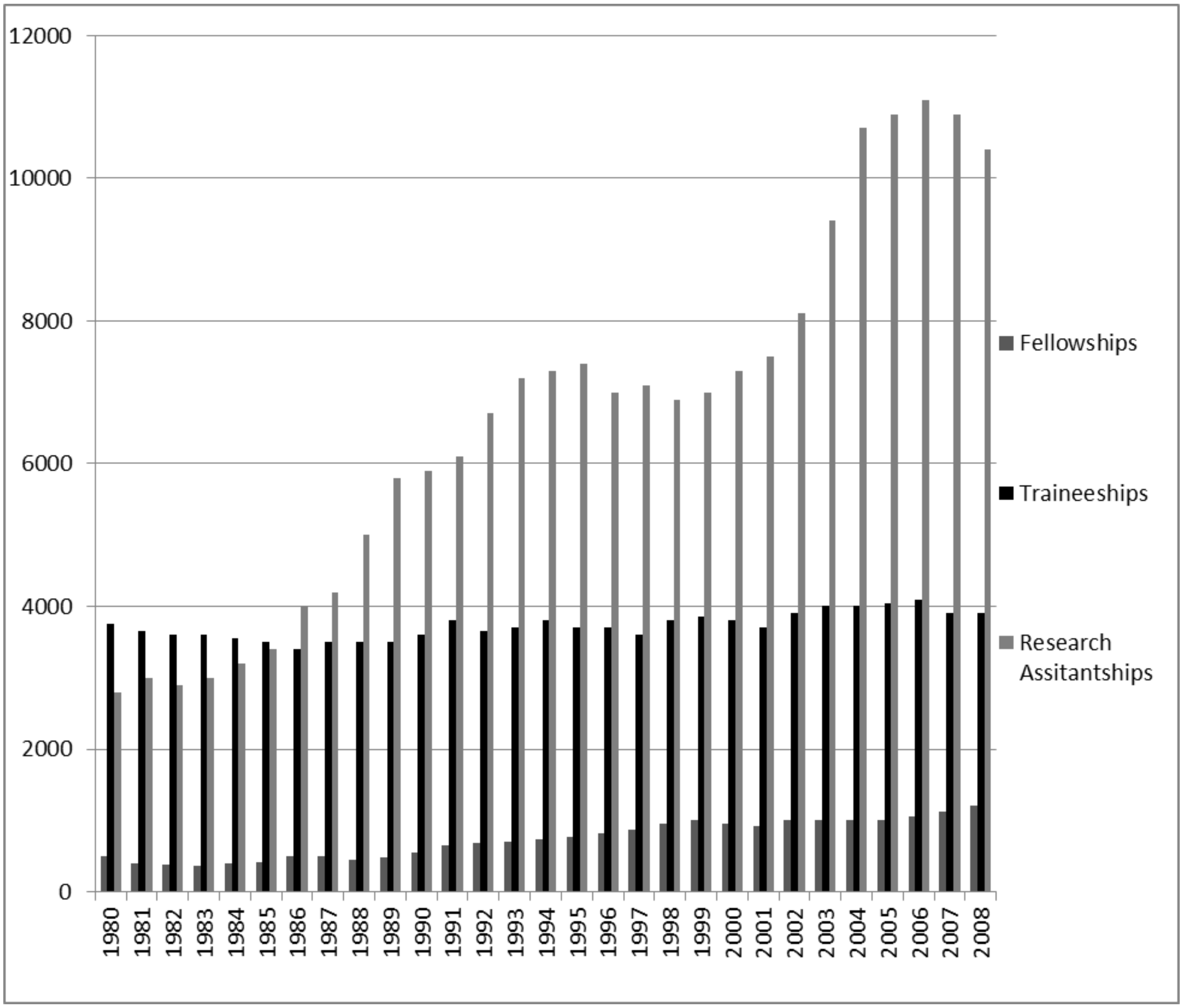


Source: NSF Webcaspar

5.2 The 1980s-1998

The relative importance of federal funding for university research continued to decline during the 1980s and most of the 1990s (Figure 3). This time it was not because the Federal government's expenditures for university research were flat, however, but rather that they were increasing at a slower rate than the contributions of other sectors—especially those of business and industry, whose expenditures for university research grew by a factor of 3.7 during the period, and of universities themselves, whose contributions to their own research grew by a factor of 3.9 during the period. During the same period, funds from state and local government for research, funds from the federal government and funds from other sources increased by a factor of 2.2.

Figure 6: NIH Support of Graduate Students



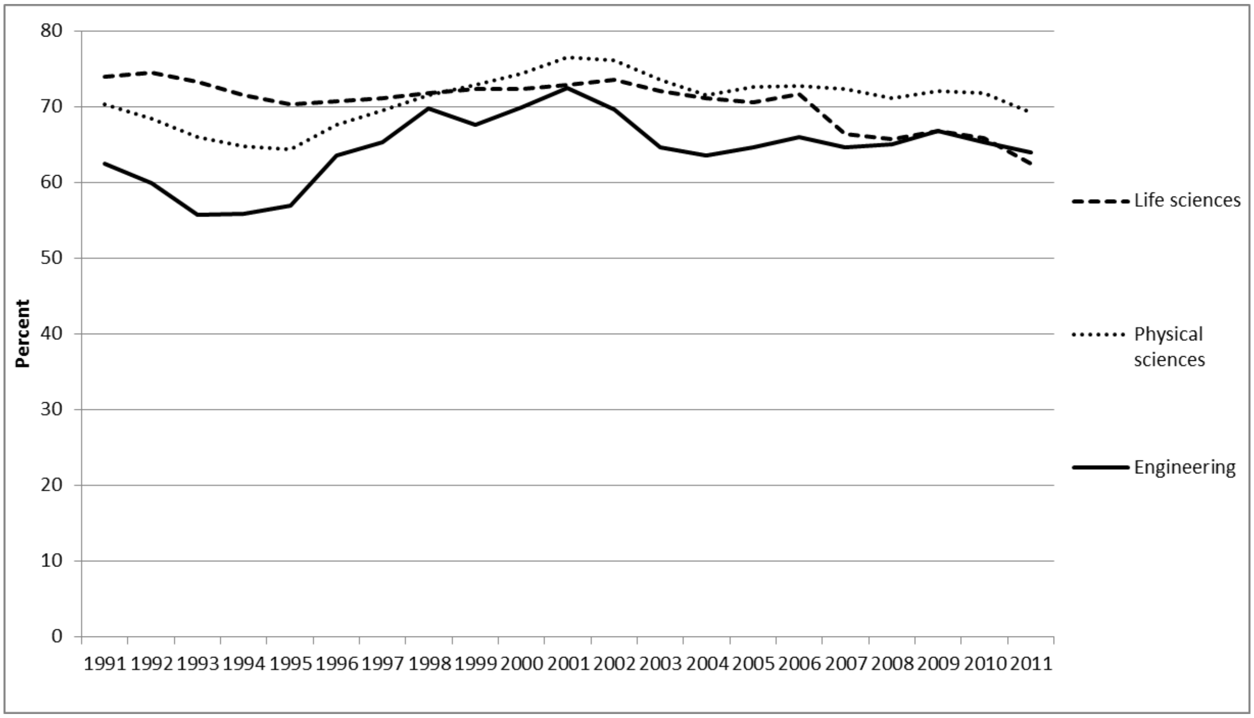
Source: (National Research Council, 2011, p. 47)National Research Council. 2011.

The number of universities and colleges receiving research contracts and grants from Federal agencies rose during the 1980s, especially the number receiving NSF funds (Figures 4). The number receiving NIH funds, which had remained remarkably constant for many years, finally began to increase. The concentration of resources, as measured by the HHI index and the percent received by top ten institutions continued to decline for all agencies, save NIH where it stayed constant (Figure 5 and Figures A.1-A.5).

PhD production, which had initially declined and then been almost flat during the 1970s and early 1980s, began to increase. Growth was particularly notable in engineering, and slightly later in the period in the biological sciences. Growth was also notable at non-Research I institutions. PhD production became increasingly less the domain of elite institutions.

Registered time to degree continued to increase in all fields. In 1993, for example, it was 6.7 years in the physical sciences, 6.5 in engineering, and 7.0 in the life sciences compared to 6.1, 5.9 and 6.2, respectively, ten years earlier (Table 3). Increasingly graduate students were supported as graduate research assistants rather than on fellowships or training grants. At NIH, the number of training positions for predoctoral support remained almost constant; the number of individuals supported on faculty grants as research assistants more than doubled between 1980 and 1990 (Figure 6).

Figure 7: Percent of Doctorates Recipients from U.S. Universities with Definite Commitments, 1991-2011

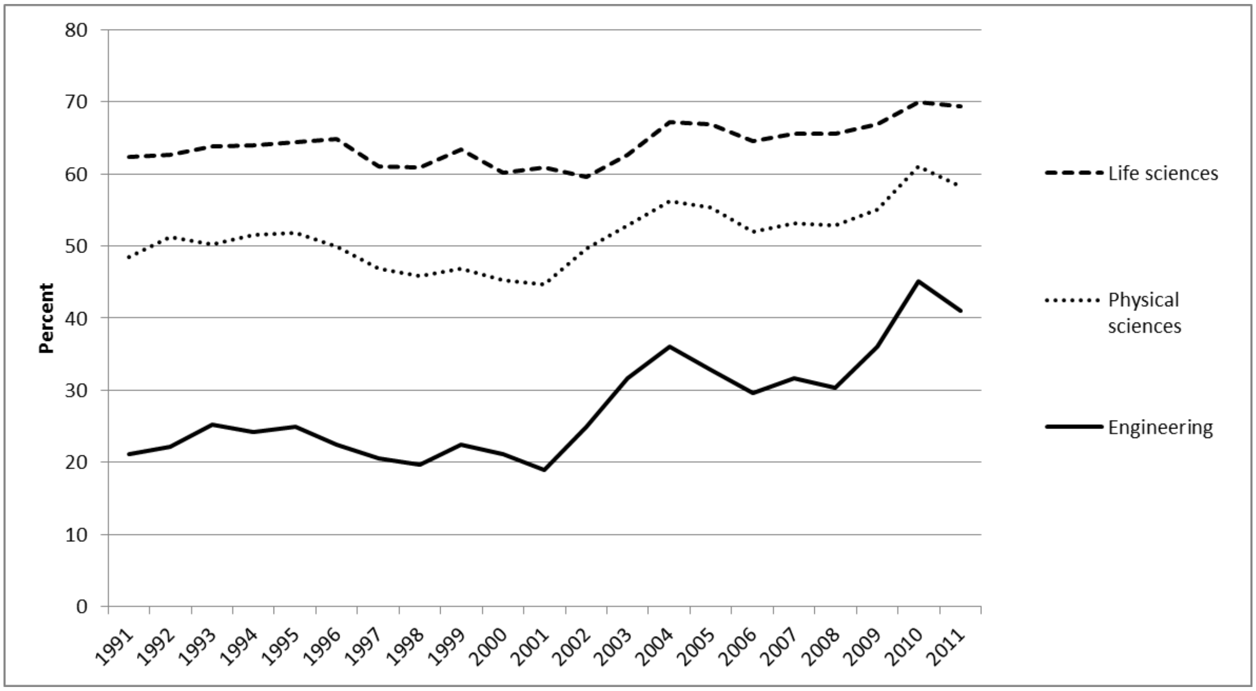


Note: Definite commitment refers to a doctorate recipient who is either returning to pre-doctoral employment or has signed a contract (or otherwise made a definite commitment) for employment or a postdoc position in the coming year (National Science Foundation, 2012).

The percent of new PhDs in engineering and in the physical sciences with definite plans at the time they received their PhD declined substantially in the early 1990s, only to increase dramatically in the mid-to-late 1990s as the dot.com industry began to hire aggressively (Figure 7.) By 2001, however, with the demise of the dot.com bubble, the career prospects of newly trained engineers had begun to deteriorate considerably; prospects for those in the physical sciences also had begun to deteriorate, but to a lesser extent. A decreasing proportion had definite commitments at the time they graduated and an increasing percent of these definite commitments began to be for postdoctoral positions (Figure 8).

Definite commitments for new PhDs in the life sciences also deteriorated during the middle part of the 1990s. The percent taking a postdoctoral position increased and/or remained high. Sufficient concern was expressed regarding their career prospects to cause the National Research Council (NRC) to form a committee to study trends in the early careers of life scientists. The chair was Shirley Tilghman of Princeton. The committee made several recommendations, including restraint in the growth of the number of graduate students in the life sciences, the dissemination of information on the career outcomes and prospects of young life scientists, the improvement of the educational experiences of graduate students, and enhancement of opportunities for independence of postdoctoral fellows.

Figure 8: Percent of Doctorate Recipients from U.S. Universities with Definite Commitments Taking a Postdoctoral Position, 1991-2011



Source: (National Science Foundation, 2012)

The university community did not rush to embrace the committee's recommendations. Graduate programs continued to grow, the ratio of individuals supported on graduate research assistants to training grants and fellowships inched upward, no effort was made to disseminate job market information. The reason for the failure is clear: the incentives of principal investigators and the university community were incompatible with the recommendations, and the committee had virtually no control over levers that could influence these incentives—such as the requirement that metrics for evaluating a faculty's grant include information on the career outcomes of those trained in his or her lab.

5.3 University contributions to research and the cost of equipment

Before turning to a discussion of the doubling of the NIH budget and the period that followed, two trends of the 1980s and 1990s that continue today deserve special comment. One is the increasing share that universities contribute to research and development (Figure 3); the second is the increasing expenditures that universities make for research equipment.

At least two factors have contributed to universities picking up a larger and larger share of research funding since the mid-1960s. First, and as noted above, a constant theme of university administrators has been that indirect cost rates fail to cover the institution's costs for research, a problem that became more acute after OMB established limitations on federal indirect costs in 1991 and caps were put on expenses that universities could claim in a number of areas.

A second reason that universities began to pick up a larger and larger share of the cost for research relates to the growing practice of providing start-up packages for newly hired faculty.[23] Such packages not only play an important role in recruiting senior faculty. They also provide the time and resources that newly minted faculty need to develop the preliminary results to place them in a competitive position for receiving grants, containing funds for graduate research assistants, postdoctoral researchers, supplies, and, in many instances, equipment. At Cornell University, for example, equipment expenditures represent 60 or more percent in one-third of the start-up funds provided new hires recently; in one-half of the start-up packages they represent between 25 and 40 percent.[24]

Start-up packages can be quite large. A 2003 survey found that the average of mean start-up packages offered by institutions for an assistant professor in chemistry was $489,000; in biology, it was $403,071.[25] These are not modest sums. They represent four to five times the starting salary that the institution paid a junior faculty member at the time. At the high end, it was $580,000 in chemistry, and $437,000 in biology. For senior faculty, start-up packages averaged $983,929 in chemistry (high end: $1,172,222) and $957,143 in biology (high end: $1,575,000) (Ehrenberg, Rizzo, & Jakubson, 2007). More recent data for start-up funds at a private Research I university show packages between $500,000 and $1,178,000 between FY08 and FY10 for assistant professors in biochemistry and biology.[26] Those in chemistry for the same period were between $535,000 and $635,000. Start-up funds for an associate

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[23] The growing requirement of federal agencies that universities provide matching funds in grant proposals is a third factor which has led to increased contributions of universities towards research (Ehrenberg, American Higher Education in Transition, 2012).

[24] Data provided by Robert Buhrman, Cornell University.

[25] The survey was administered to three to six science and engineering departments at 222 research and doctoral institutions. The average means reported are drawn from the responses of the 572 department chairs who replied (with a response rate of 55 percent) (Ehrenberg, Rizzo, & Jakubson, 2007).

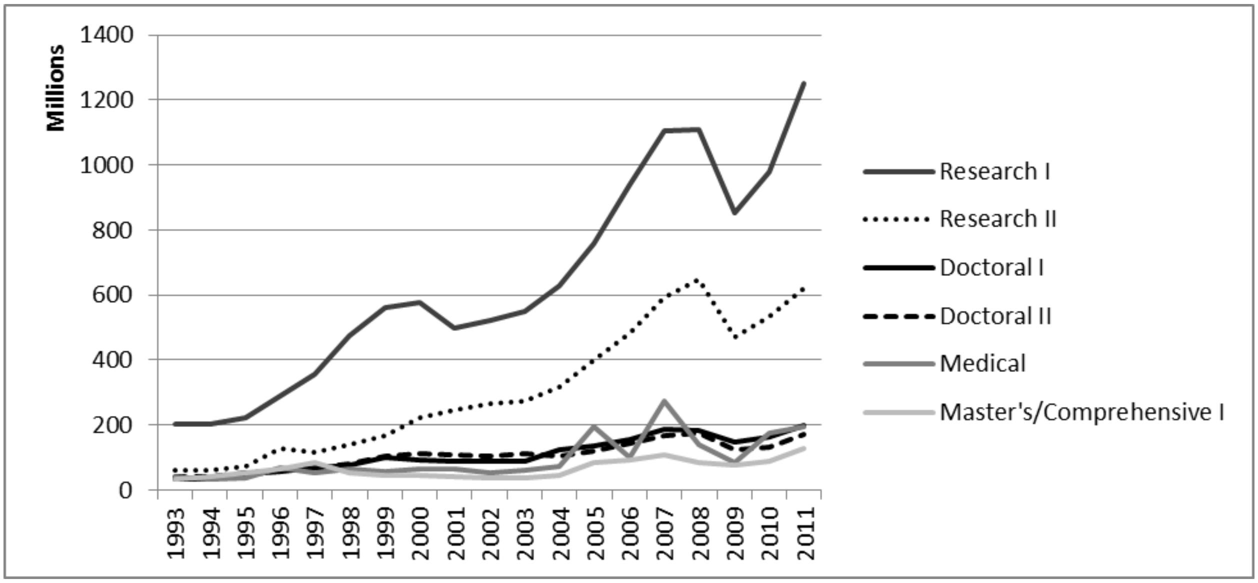
[26] The range in the value of the packages is due in part to the practice of the institution to often make an offer with two start-up package numbers: a guaranteed support level and an additional amount that would be made available if the candidate had difficulty getting funding within three years.

professor of chemistry were $1,178,000. Start-up packages can be considerably higher at medical schools where a full professor reportedly can receive a package of $5 million or more in 2013.

No one has done the accounting regarding where institutional funds for research come from, but research by Ehrenberg and coauthors supports the view that students pick up part of the costs, especially at private institutions, where the student-faculty ratio grows as internal funding for research grows, and where tuition levels increase as internal funding for research grows (Ehrenberg, Rizzo, & Jakubson, 2007). The first effect is smaller at public institutions, and the tuition effect is not discernable for public institutions.

The question remains, however, as to where universities get the majority of funds to invest in research, since clearly only a small portion is borne by students in the form of higher tuitions and larger class size. One obvious source is endowment income, especially given that endowments have grown significantly over time, as can be seen in Figure 9. Indeed, despite the beating that endowments took in 2009 and regardless of Carnegie classification, endowments are currently at their all-time high at many institutions in terms of 2011 constant dollars.

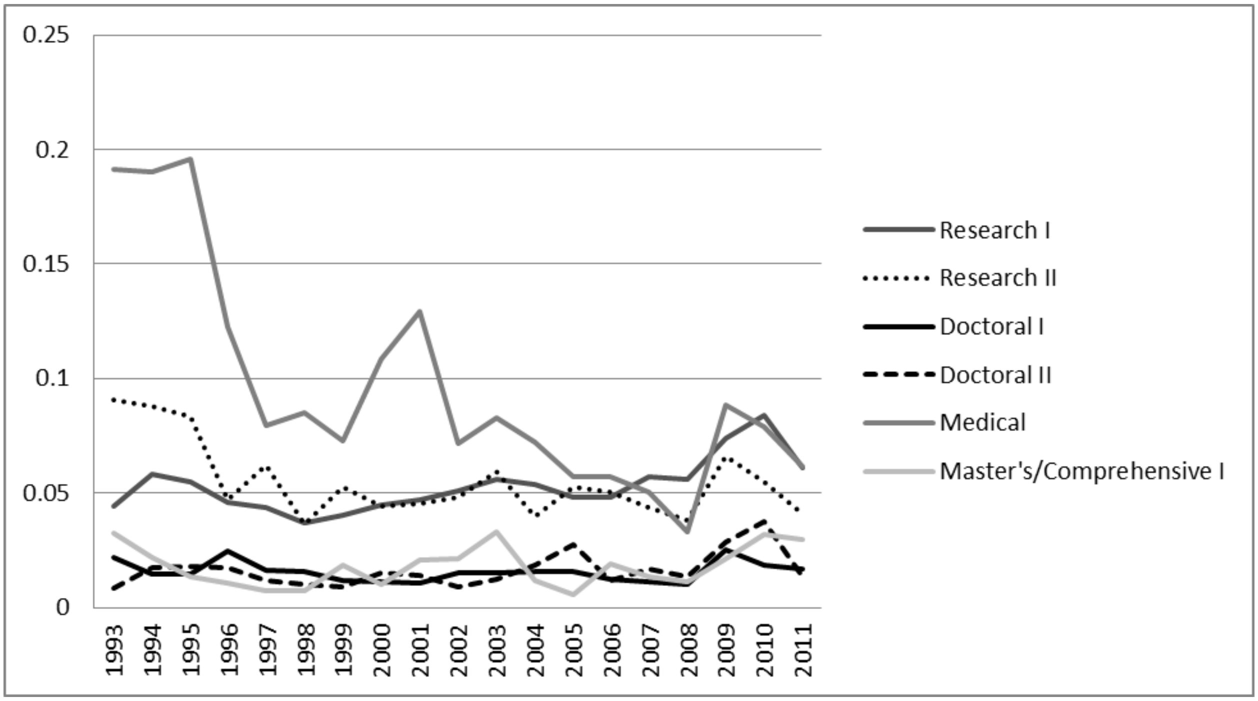
Figure 9: Median of Endowment Funds in Constant 2011 dollars by Carnegie Classification, 1993-2011



Source: Data provided by the Common Fund for Nonprofit Organizations

Figure 10 explores how the growth in internal university R&D expenditures relates to this growth in endowment, plotting the median ratio of institutional expenditures on R&D to the value of the institution's endowment over time by Carnegie classification. We would not, of course, expect to find a high ratio, given spending rules associated with most endowments. And we find, on the whole, that the ratios are fairly modest--except at medical institutions where in the early years they approached .2. Furthermore, we find that on the whole, at least through the late 1990s, the ratio declined over time. Thereafter the ratio of research expenditures to endowment rose slightly at Research I and Research II institutions. The ratio for Research I continued to increase, matching in certain years that at medical institutions. That at Research II institutions plateaued or slightly declined, only to increase as a result of the spectacular fall in endowment values in 2009. Reflecting perhaps their desire to move up in the rankings, the ratio of expenditures to endowment increased at masters levels institutions during certain periods, as did that at Doctoral and Doctoral II.

Figure 10: Median Ratio of Institutional Expenditures for University Research and Development to Endowment Value, 1992-2011



Note: Ratio computed for institutions reporting in that year a positive R&D expenditure value; Source Webcaspar and the Common Fund for Nonprofit Organizations

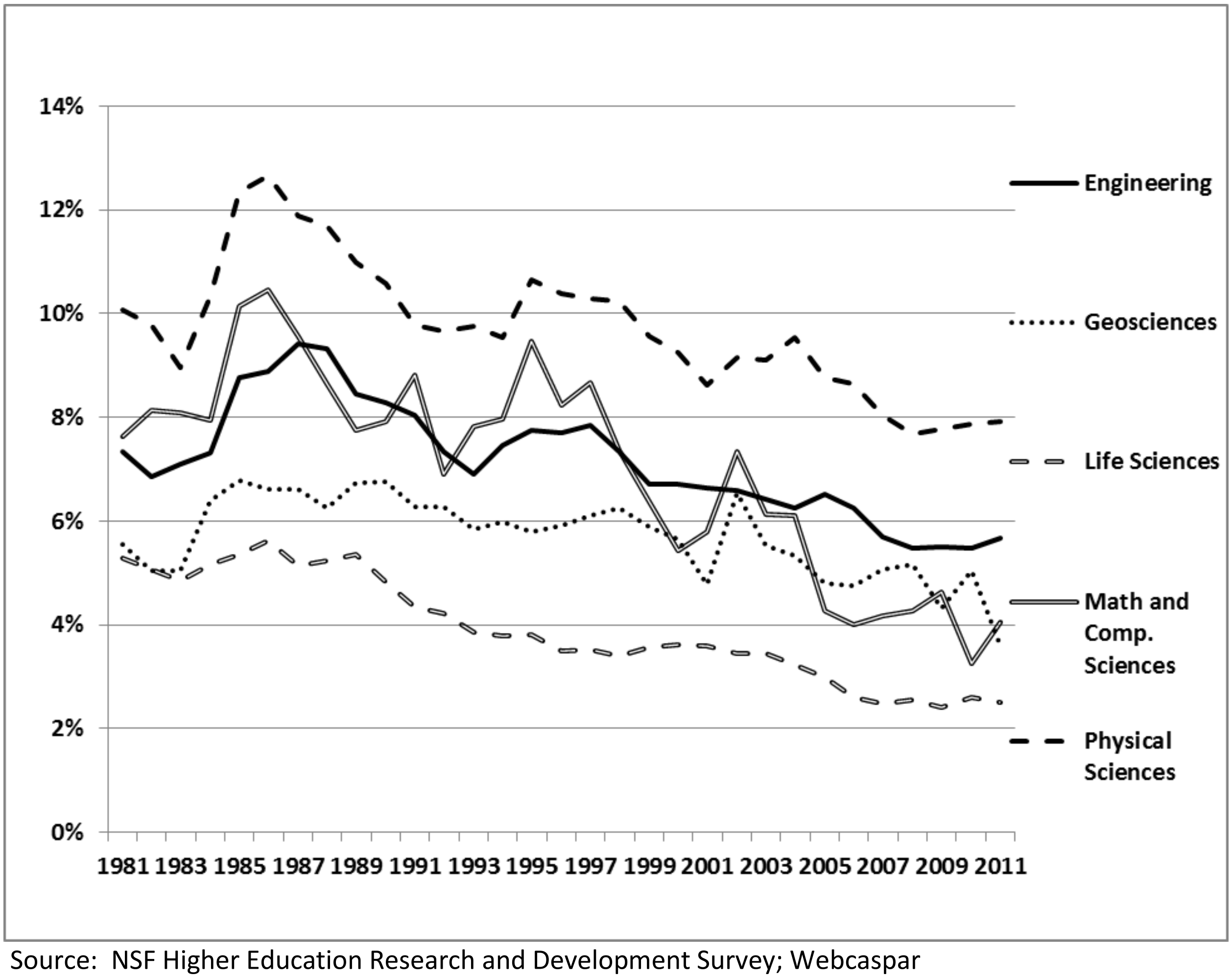
We cannot, of course, conclude from this exercise that endowment is the source of university expenditures on research. But our findings suggest that there has not been a dramatic increase in the research expenditures of universities relative to their endowments. At most institutions, at least up to the mid-2000s, expenditures grew at a slower pace than did the value of the endowment. Our findings are consistent with the growing importance universities place on fund-raising for scientific research (Murray, 2012) (Mervis, 2013).

The second trend that deserves comment relates to the amount that universities spend on equipment for research—either out of their own funds or the funds provided by others--which, in real terms, almost doubled in the six-year period between 1984 and 1990 and almost doubled again in the 1990s. Today it stands at approximately 2.5 billion dollars in 2005 dollars. In terms of level, expenditures for equipment are the greatest in the life sciences, reflecting strong funding, followed by engineering and the physical sciences. Equipment intensity also varies considerably by field (Figure A.6). Not surprisingly, the physical sciences typically spend the largest portion of their research budgets on equipment—anywhere from 9 to 12.5 percent. The life sciences, which range from 2.5 percent to 5.0 percent, spend the least (Figure 11).

Faculty and administrators often express the concern that the cost of equipment is rising and that as a result they are forced to spend greater amounts of their research funds on equipment. Not only is the price going up, but new types of equipment, such as sequencers and confocal microscopes, have become necessary, if not for the lab, for core facilities at a university.

While equipment prices have undoubtedly risen over time—one researcher bemoaned how X-ray equipment which used to cost $250,000 now costs about $1.5 million--the data do not support the idea that the percent of total research and development expenditures spent on equipment has been increasing over time. Indeed, as Figure 11 shows, with the exception of the mid-1980s, the trend has been definitely downward. There are at least two possible explanations as to why this fact is at odds with the perceptions of deans and faculty. First, the capability and efficiency of the equipment has been

Figure 11: Percent of R&D Funds Spent on Equipment by Field, 1981-2011



Source: NSF Higher Education Research and Development Survey; Webcaspar rising faster than cost. As a result, universities are able to run core facilities where faculty share a common piece of (expensive) equipment. Second, some of the major costs occur outside the R&D equipment accounting system of universities. For example, a share in SER-CAT, which allows members access to a synchrotron beamline at Argonne National Labs, costs $250,000. Yet the synchrotron beamline built at Argonne cost approximately $7 million to construct. Neither the share price nor the actual cost of construction is likely to show up in the university R&D expenditure accounts for equipment.[27]

5.4 NIH doubling and years following the doubling

It is tempting to assume that more funding is the answer to many of the problems that plague the university research system. One would expect additional funds to translate into higher success rates and be accompanied by improved job prospects, especially for young researchers. But anyone who thinks so should be careful what they wish for. The doubling of the NIH budget in nominal terms between 1998 and 2002 ushered in a number of problems. By the time it was over, success rates were no higher than they had been before the doubling. By 2009, and in part because of the real decrease that the NIH experienced in the intervening years, success rates were considerably lower than they had been before the doubling (Figure 2). Faculty were spending more time submitting and reviewing grants, in part because an increased proportion of grants were not approved until their last and final round.[28] Moreover, there is little evidence that the increase translated into a substantial improvement in the job prospects of newly minted PhDs, as had been the case in the 1950s and 1960s when government support for research expanded. Yes, the doubling brought more jobs, but the supply of new PhDs grew faster than the demand for new hires. The percent of newly-minted PhDs in the life sciences with definite commitments declined from 2002 on (Figure 7) and the percent taking postdoctoral positions rose (Figure 8).

A major cause of this seeming paradox was the response of universities to the doubling. Some universities saw the doubling as an opportunity to move into a new “league” and establish a program of “excellence.” Others saw it as an opportunity to augment the strength they already had. For others still, expansion of their existing programs was simply necessary if they were to remain a player in biomedical research. Regardless, the end result was that the majority of research universities went on an unprecedented building binge. Research space in the biological, biomedical and health sciences increased by one-third during the six year period between 2001 and 2006 (Figure 12).

Not surprisingly, the number of applicants for new and competing research projects grew. Success rates, which were over 30 percent at the beginning of the doubling, fell to 20 percent by 2006 (Figure 2). One reason for the decline in success rates was the substantial growth in budgets accompanying the

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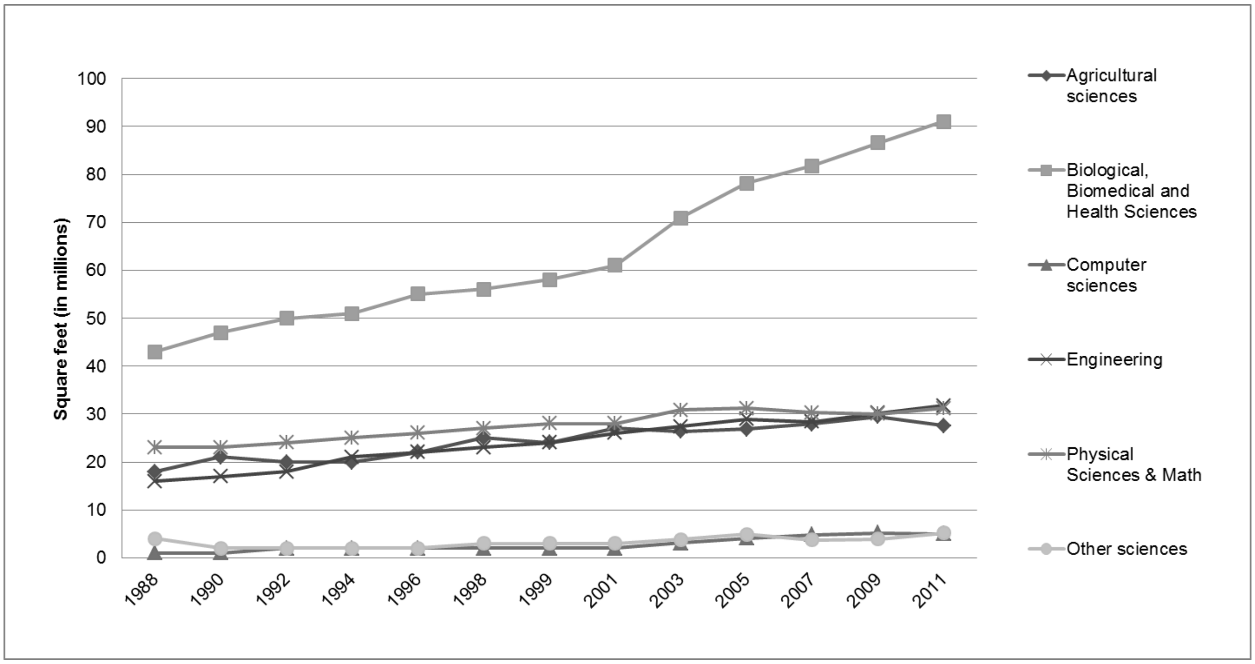
[27] The Southeast Regional Collaborative Access Team (SER-CAT) was established in 1997. Several universities and research groups purchased more than one share. See (Stephan, How Economics Shapes Science, 2012, pp. 93-95)

[28] Early in the 21st century, 60 percent of all funded R01 proposals were awarded the first time they were submitted. By the end of the decade only 30 percent were awarded the first time. More than one-third were not approved until their last and final review (Stephan, 2012). This not only took time and delayed careers, but the perception was that these “last chance” proposals were favored over others, creating a system that, according to Elias Zerhouni, awarded “persistence over brilliance sometimes” (Kaiser, 2008).

proposed research: in 1998, the average annual budget of the typical grant was $247,000; by 20009, it had grown to $388,000 (Stephan, 2012, p. 142). One reason for the increase was that more faculty were on soft-money positions and thus writing off a larger proportion of their salary.

Figure 12: Net Assignable Square Feet for Research by Field and Year



Source: (National Science Foundation, 2013)

Some of the new grants during the doubling went to researchers who had heretofore not received funds. But the vast majority of new grants went to established researchers: the percentage of investigators who had more than one R01 grant grew by one-third during the doubling, going from 22 percent to 29 percent. The number of first-time investigators grew by less than 10 percent. Young researchers were at a disadvantage competing against more seasoned researchers who had better preliminary data and more grantsmantship expertise. The increased number of grants for experienced investigators and minimal growth in grants for first-time investigators resulted in a dramatic change in the age distribution of PIs. In 1998, less than a third of awardees were over 50 years old: almost 25 percent were under 40. By 2010, almost 46 percent were over 50, and less than 18 percent were under 40. More than 28 percent were over 55 years old (Stephan, 2012, p. 143). Faculty staffed these labs with postdocs and graduate students. The number of postdocs in the life sciences grew by almost 33 percent between 1997 and 2008. PhD production grew by almost 38 percent (Figure 2).

6.0 Taking Stock

From the perspective of the early twenty-first century, it is clear that *The Endless Frontier* contributed to building the university research enterprise. It also set in motion forces that would transform it. Universities in the early 21st century are a far cry from those of the 1940s, having been transformed from a focus on educating students and taking care of patients, to placing a high—if not the highest—

value on research. The incentives that have evolved over time have encouraged this transformation. Universities are routinely ranked on the amount of federal funds they receive; membership in the prestigious American Association of Universities (AAU) puts considerable emphasis on federal funds, as does the Carnegie Classification. The number of doctoral degrees awarded also plays a key role in certain rankings.

Bush would be astonished at the capacity that has been built: The number of research universities has grown from a mere ten to fifteen, to more than 100, depending upon definition (National Research Council, 2012). The number of institutions that are funded has grown considerably, from the 120 universities and medical schools supported by NIH in 1948 to the 556 supported today. At NSF, the growth has been even more impressive, going from 60 to 628. Overall, the number of institutions receiving federal funds has grown from slightly fewer than 600 in 1971, the first year for which data are readily available, to over 900 in 2009 (Figure 4). By any measure, funds are less concentrated. The percent of federal research funds going to the top ten institutions has decreased by almost 50 percent; the HHI index, which has always been relatively low, with minor exceptions for DOD funding, has declined by about 30 percent (Figure 5). The decrease in concentration has occurred at all agencies, save NIH, where top universities and medical schools have been remarkably successful at holding on to their share, despite the increased number of universities and medical schools supported by NIH.

Concomitantly, the number of universities offering doctoral training in science and engineering has grown by more than five fold. The number of degrees awarded has grown by a factor of 17. The percent of degrees awarded by top ten and top twenty five institutions has decreased substantially (Table 2) as has the percent awarded by Research I institutions.

The Endless Frontier also set in motion forces that transformed the relationship between universities and the federal government. No longer need the federal government cajole universities and faculty into submitting grants. Long ago the tables turned. Universities now spend considerable energy and funds convincing federal agencies to provide more resources, hiring lobbyists to work on the university's behalf to direct federal (and state) funds to the university[29] and joining forces to issue reports that make the case for more support from the federal government. The tradition was established more than 50 years ago with the Seaborg report. It was reaffirmed in 2012 with the NRC report "Research Universities and the Future of America" which pressed, among other things, for moving certain costs covered by indirect to direct costs, federal funding for a "strategic investment program," and a reduction or elimination in regulations that increase administrative costs (National Research Council, 2012).

As the tables turned, the way in which graduate students are supported by federal funds dramatically changed as well. The system Bush envisioned was designed to build future research capacity by supporting graduate students and postdocs on fellowships or training grants. While these mechanisms for federal funding remain in place, their importance has paled as increasing numbers of students are supported as research assistants on faculty members' grants and postdocs on stipends paid from grants. The shift means that federal funds are no longer directed at building future research capacity but

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[29] See for example, the work of De Figueirdo and Silverman (De Figueiredo & Silverman, 2007).

toward getting the research done today. This shift in mechanisms of support is likely reflected in lengthened time to degree.

Universities increasingly expect faculty to cover part if not all of their salary on grants. The practice began sometime in the 1950s and spread fairly rapidly, so that by the late 1960s almost half the medical school faculty in the country received some salary support from federal grants. Today, medical school faculty, even those who are tenured, routinely cover close to 100 percent of their salaries on grants. Universities, except for a handful of elite institutions such as Princeton and Caltech, routinely expect faculty to write off part of their salaries on grants and hire faculty in soft money positions with the expectation that they will cover all of their salary on grants.

In many ways universities in the United States have come to resemble high-end shopping malls. They are in the business of building state-of-the art facilities and a reputation that attracts good students, good faculty, and resources. They turn around and lease the facilities to faculty in the form of indirect costs on grants and the buyout of salary. Some of these faculty are in soft money positions, in essence paying for the opportunity to work at the university, receiving no guarantee of income if they fail to bring in a grant. To help faculty establish their labs—their firm in the mall—universities provide start-up packages for newly hired faculty. After three years, faculty are on their own to get the necessary funding for their lab to remain in business.

The shopping mall model has led universities to spend an increasing amount of their resources in support of research. Some of this is for start-up packages; some is for matching funds required by federal agencies, and some is to defray costs not covered in indirect. Not only are universities spending more, but their share of research costs has increased, going from a low of 8.1 in 1963 to a high of 20.4 percent in 2009.

The shopping-mall model also encourages universities to construct new research facilities, increasing their capacity to rent out space to faculty. The expectation is that “the space will be paid from a combination of direct and indirect costs funded by the federal government.”[30] In the past ten to fifteen years, this new space has been heavily concentrated in the biomedical sciences. Indeed, two-thirds of the increase in net assignable square feet for research that has occurred in the past ten years was in the biological, biomedical or health sciences (Figure 12). Faculty use the space and equipment to create research programs, staffing them with graduate students and postdocs who contribute to the research enterprise through their labor and fresh ideas.

External funding, which was once viewed as a luxury, has become a necessary condition for tenure and promotion. It is even more important for faculty on soft money positions or for those whose tenure does not come with a salary guarantee. Yet external funding has become increasingly more difficult to get as federal funds, excluding ARRA, have remained almost flat during much of the first decade of the 21st century and the number of individuals seeking funding has continued to increase. Reflecting this situation, success rates at NIH and NSF stood at close to historic lows, hovering around 20 percent (Figure 2).

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[30] Shirley Tilghman as quoted in (Mervis, 2013, p. 1399).

7.0 Stresses to the System

The university research system that has grown and evolved since the publication of *The Endless Frontier* almost seventy years ago faces a number of challenges that threaten the health of universities and the research enterprise and have implications for discovery and innovation. Five are discussed in this closing section.

7.1 Risk Aversion

In today's environment, grants are often scored for "doability," selected because they are "almost certain to work" (Alberts, 2009). At the time a proposal is submitted, it is routine that two of the three objectives have been completed (Azoulay, Zivin, & Manso, 2012). To quote the Nobel laureate Roger Kornberg, "If the work that you propose to do isn't virtually certain of success, then it won't be funded." Yet, as Kornberg continues, "the kind of work that we would most like to see take place, which is groundbreaking and innovative, lies at the other extreme" (Lee, 2007). This was not always the case: there is a perception among older scientists that peer review used to be a different game, with reviewers focused on "ideas, not preliminary data" (Kaiser, 2008). It is not only the peer-review system that fosters risk aversion. The Defense Advanced Research Projects Agency (DARPA), which once boasted that "it took on impossible problems and wasn't interested in the merely difficult," has increasingly shifted to funding research that is more near-term and less risky (Ignatius, 2007).

The preference to fund research that is "doable" increases when funding is difficult to come by, which has been the case for the last ten years as measured by success rates at NIH and NSF (Figure 2). One reason is that agencies feel pressed to report successful research (Petsko, 2012). Another is that it is easier to justify funding safe bets when funding is in short supply. The recently released ARISE report (Advancing Research in Science and Engineering) from the American Academy of Arts and Sciences concluded that in tight times "reviewers and program officers have a natural tendency to give highest priority to projects they deem most likely to produce short-term, low-risk, and measurable results" (American Academy of Arts and Sciences, 2008, p. 27).

The preference on the part of agencies to fund "doable" research need not, of course, translate into faculty taking up less risky lines of research, since the receipt of funding can be viewed as a prize awarded to individuals who have almost completed the research before applying for funding (Azoulay, Zivin, & Manso, 2012). But the pressure on faculty to receive funding quickly in their academic career—at the end of their third year at many universities, if not sooner—means that faculty can ill afford to follow a research agenda of an overly risky nature. They need tangible results and they need them quickly. The pressure is even greater for those in soft money positions. Moreover, the fact that grant renewals have a much higher chance of being positively reviewed, be the renewals formal or de facto, discourages faculty from taking up new research agendas once they have established a line of research.

Should this proclivity for risk aversion be of concern to the university community and more importantly to society in general? Yes: First, there is the issue of the composition of the research portfolio. It is pretty clear that if everyone is risk averse when it comes to research there is little chance that transformative research will occur or that the economy will reap significant returns from investments in research and development. Incremental research yields results, but in order to realize substantial gains from research not everyone can be doing incremental research. Second, one of the main reasons that Bush, and those who adopted his proposed course of action, placed research in the university sector was the view that society needed to undertake basic research of an unpredictable nature and that universities were precisely the place to conduct risky research because they "provide the environment which is most conducive to the creation of new scientific knowledge and least under pressure for immediate, tangible results" (Bush, 1945, p. 7). Yet the system that has evolved does precisely the opposite of this, placing pressure on faculty for quick, predictable, results. Finally, and more generally, a fundamental rationale for government support of research is the notion that research is risky. As laid out by Kenneth Arrow, society has a tendency to underinvest in risky research without government support (Arrow, 1955).

7.2 The tendency to produce more PhDs than the market for research positions demands

A primary reason of Vannevar Bush for advocating the establishment of the National Science Foundation and ratcheting up funding for the National Institutes of Health was the concern that the US had exited World War II with a severe lack of research capacity. Thus, a goal of the federal government, operating in cooperation with universities and medical schools, was to build research capacity by training new researchers. It was also to conduct research. However, it was never Bush's vision that training be married to funding for research. Yes, good training required a research environment and good research required assistance, but Bush did not see research grants as the primary way to support graduate students. Nor did he see them as the source of support for postdoctoral study. Rather, he argued that, in order to build capacity, graduate students and postdocs should be supported on fellowships.

It did not take long for the system to change. Faculty quickly learned to include graduate students and postdocs on grant proposals and, by the 1960s, PhD programs had become less about capacity building and more about the need to staff labs and teach classes. The caution of the Seaborg report regarding the harm that research assistantships and teaching assistantships could do to a young scientist went unheeded (The President's Scientific Advisory Committee, 1960, p. 17). The structure of a university lab, with the principal investigator at the top, followed below by postdocs and then by graduate students, began increasingly to resemble a pyramid scheme where, in order to staff their labs, faculty recruit PhD students into their graduate programs, providing them tuition and a research assistantship and the implicit assurance of interesting research careers.

The pyramid scheme works as long as the number of jobs grows sufficiently to absorb the newly trained. Yet by most indications, the system that has evolved, with demand based on the need to staff faculty labs, is producing more PhDs than the market for future research positions demands given current and projected levels of funding for research. One indication of this is the rising percent of individuals who do not have a definite commitment at the time they receive their PhD (Figure 7). Another is the rising percent of those definite commitments that are for postdoctoral positions (Figure 8). While in certain fields, such as engineering and the physical sciences, a sizeable component of this is cyclical, in the field of the biomedical sciences it is chronic and has been so at least since 1976 when an NRC report evaluating training grants concluded that a "slower rate of growth in labor force in these fields was advisable" (National Research Council, 1994, p. 98). PhD recipients, as a recent NIH workforce study committee documented, increasingly must find jobs that do not utilize their research training (National Institutes of Health, 2012).

Such a model for staffing labs is inefficient in the sense that substantial resources have been invested in training these scientists and engineers. The trained have foregone other careers—and the salary that they would have earned—along the way. The public has invested resources in tuition and stipends. If these "investments" then enter careers that require less training, resources have been used inefficiently. There are less expensive ways to train high school science teachers, as a recent NRC report suggested as a career alternative (National Research Council, 2011), or a better way to create venture capitalists with a sufficient understanding of science, or a better way to train individuals to represent and service new pharmaceutical products.

Yet questions concerning training outcomes often fall on deaf ears among faculty and university administrators, who, as one report stated, see the current system as "incredibly successful" and resist recommendations such as those put forward by the Tilghman committee in the late 1990s (National Research Council, 2011). The alternative, to employ long-term staff scientists in the lab, is resisted. One reason is that a permanent staff would cost more. While this is indisputable in the short run, it fails to account for the cost savings that would be realized if the system were not constantly staffing labs with a new crop of graduate students and postdocs. Adherence to the system also threatens the long-run health of the research system, by discouraging individuals who take career outcomes into their decision-making process from entering careers in science.[31]

7.3 Overexpansion of research facilities

In recent years, universities have gone on a building binge, constructing a substantial amount of new research space which led to a 30 percent increase in net assignable square feet for research between 2001 and 2011. Most of this increase is for facilities in the biological, biomedical and health sciences—a response of universities to the doubling of the NIH budget (Figure 12). Some of this space has been paid for by private philanthropy. At MIT, for example, David Koch contributed $50 million to the construction of an institute for cancer research that bears his name (Murray, 2012). But in a number of instances, campuses did not have the funds to construct the new buildings but instead did so by floating bonds, assuming that the debt would be recovered through increased grant activity engendered by better facilities housing more research-active faculty. A 2003 survey of medical schools by the AAMC found

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[31] Smart young people put up with this system for several reasons. First, until recently, there has been a ready supply of funds to support graduate students and research assistants and to hire postdocs. Second, factors other than money play a role in determining who chooses to become a scientist. One factor in particular is a taste for science. Dangle stipends and the prospect of a research career in front of star students who enjoy solving puzzles and it is not surprising that some keep coming, discounting the muted signals that research positions are in short supply. Overconfidence also plays a role: students in science persistently see themselves as better than the average student in their program—something that is statistically impossible. Fourth, when it comes to promoting PhD study, faculty are good salesmen. Finally, PhD programs, despite recommendations of national committees, have been slow to make placement information available.

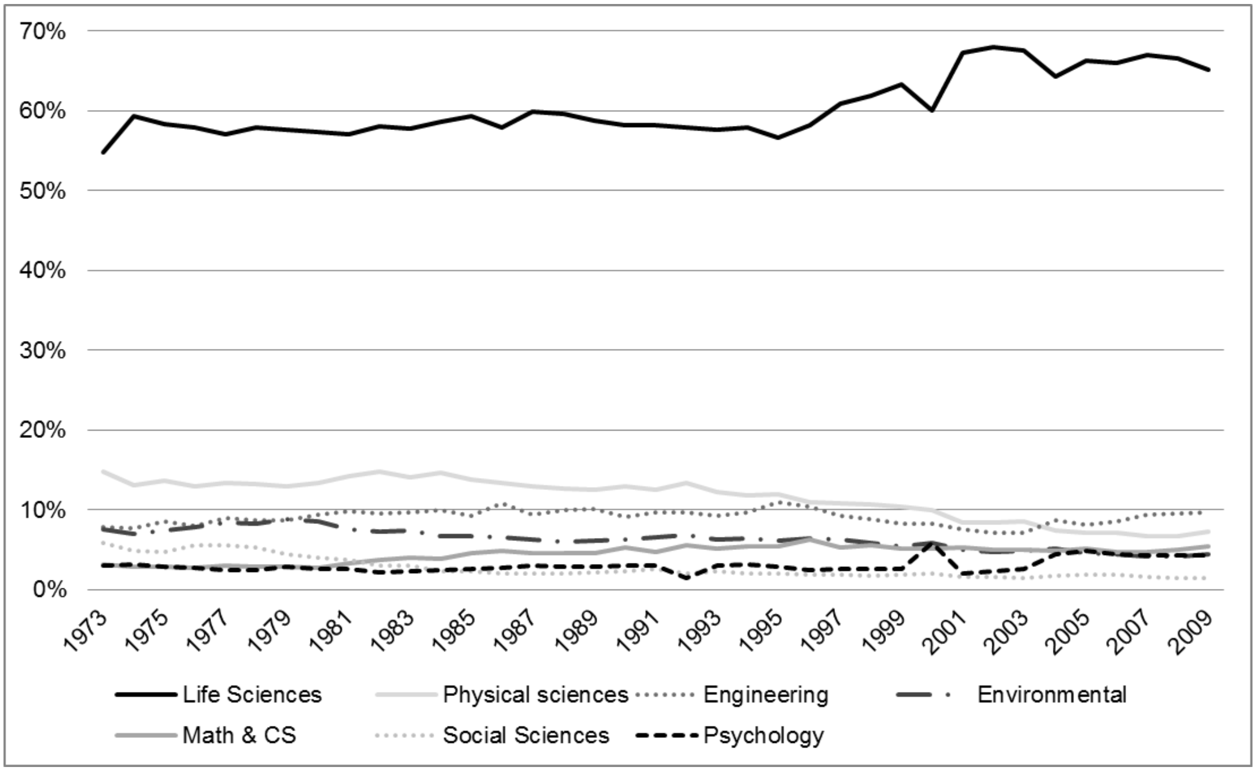
that the average annual debt service for buildings in 2003 was $3.5 million; it grew to $6.9 million in 2008 (Heinig, Krakower, Dickler, & Korn, 2007).

The brakes were applied to the NIH budget beginning in 2004 and in constant dollars the NIH budget shrank by about 4.4 percent between 2004 and 2009. It has continued to decline since, with the exception of ARRA. Success rates for NIH grants, as we have seen, declined, and universities found that revenues from grants did not live up to their expectations. The situation is not likely to improve in the near future given sequestration. This means that the only way a university can hope to cover the costs of these buildings is to outcompete over other academic institutions in bringing in grants. But, as Princeton's President Shirley Tilghman notes, "this just can't be true for every academic medical center. It does not compute" (Mervis, 2013, p. 1399). Moreover, given that very top institutions have continued to maintain their share of NIH funding, the pain is most likely to be felt by institutions that historically have not received top funding. Somebody, especially at lower-tiered institutions, is going to have to pay for this substantial expansion and it is unlikely to be the federal government. It is more likely to come through a reallocation of resources within the university.

7.4 Mix of research funding

In the steady state that Bush envisioned, funding for the natural sciences was to be 2.5 times higher than that for the medical sciences. Yet Bush's vision was never close to being realized. For the period since 1973, for which data are readily available, the share of federal university research and

Figure 13: Share of University R&D Obligations by Field, 1973-2009



Source: Stephan (2012).

development obligations going to the life sciences has, at a minimum, been above 55 percent and, after the doubling of the NIH, for a short period, approached 70 percent (Figure 13). It is relatively easy to understand the politics of why this is so. It is far easier for Congress to support research that the public perceives as directly benefiting their well-being. Moreover, a large number of interest groups constantly remind Congress of the importance of medical research for “their” disease.

One can question whether this mix of funding is efficient. Are the marginal benefits coming from another dollar spent on the biomedical sciences greater than the marginal benefits coming from another dollar spent on the physical sciences? The fourteen year increase in life expectancy in the past seventy years makes a good case that research in the biomedical sciences has a high marginal product (Stephan, 2012). But the slowed rate at which new drugs are being brought to market makes one wonder whether the marginal productivity of resources spent in the biomedical sciences is diminishing (Stephan, 2012). Furthermore, one can make a good case that spillovers from the physical sciences have made significant contributions to the economy. Some of these contributions are even in the area of health, such as the laser and magnetic resonance imaging technology.

Although no analysis is sufficiently precise to calculate the degree to which the research portfolio is out of balance, three observations lead one to think that the research enterprise might benefit if the biomedical sciences were to receive a smaller share. First, the heavy focus on the biomedical sciences is propelled by a lobbying behemoth composed of universities and nonprofit health advocacy groups that constantly remind Congress of the importance of funding health-related research. There is no comparably well-established and well-focused lobbying group on the part of other disciplines. Second, portfolio theory leads one to think that the current allocation might be out of balance. A basic tenet of investing is to rebalance one’s portfolio if a change in market valuations results in a change in the composition of the portfolio that one is holding. Yet efforts to fund research in engineering and the physical sciences, through the America COMPETES Acts, have met with limited success (Furman, 2012). Third, and particularly relevant for the discussion here, the heavy focus on the biomedical sciences affects the life of universities in a number of ways. For example, the heavy push to construct new research facilities for the biomedical sciences has consequences for facilities in other disciplines which got pushed to the back of the queue. It also has consequences for hiring. Moreover, and as noted above, there are long-run consequences, because some of the funding for these buildings was raised from the sale of bonds, and many universities are not reaping the indirect cost they had expected. It is likely that other disciplines will end up footing part of the bill.

7.5 Heavy reliance on federal funds

For many years universities have been heavily reliant on federal funds for research. Yet the future for a steady increase of federal funds looks dim. Congress has been slow to fund the America COMPETES Acts (Furman, 2012) and sequestration means that expenditures for research may well decline in real terms. Public institutions face the added challenge that funds from state and local governments for education, and research in particular, have been flat or have declined in recent years (Figure 3) and are likely to remain low in the future.

This places universities in the position of looking for alternative sources of funding for research. One source is industry, whose contribution is likely to grow as the economy picks up. But given past experience, industry is unlikely to substantially increase its share of university R&D. This leaves only two (related) sources: universities and philanthropic organizations/gifts. The first has been discussed above; the second only briefly alluded to. With regard to the latter, the percent of university research funds coming from philanthropic organizations has been growing and now exceeds that coming from industry (Feldman, Roach, & Bercovitz, 2012). Murray provides an overview of the important role that philanthropic gifts are making to university research, arguing that they account for $4 billion of the research funds of the top fifty universities in the United States (Murray, 2012).

While the increasing role of philanthropy may address a sizeable portion of the resource gap, several factors lead one to wonder if it may place new stresses on the research enterprise. First, as outlined by Murray, the majority of these philanthropic gifts are for research in the biomedical sciences. Far fewer gifts are for research in other fields, although certain foundations, such as the Gordon and Betty Moore Foundation and the W.M. Keck Foundation, routinely support research in the physical sciences and engineering. To the extent the research portfolio is out of balance, philanthropy will only add to the imbalance. Second, and related, much of philanthropic support is directed at applied medical research, with short-term research goals (Murray, 2012). Third, gifts generally supplement federal funding, rather than fill gaps in funding. Philanthropists like the idea that their gifts can be leveraged into federal funding and they share many of the health concerns of the public. Fourth, the push for gifts raises the concern that universities will focus their skills and their research on the rich and their diseases. The Medical school at Johns Hopkins has 65 full-time fundraisers. Their “caseloads” range from 12 to 30 doctors, with whom they discuss patients who might be potential donors, or to help staff identify a donor with a “qualifying” interest and connect it to their “capacity” to make a donation. The goal: “to turn ‘grateful patients’ into support for new research, faculty chairs, academic scholarships, bricks and mortar, or simply defraying the cost of running a multibillion-dollar medical center“ (Mervis, 2013, p. 1397). Finally, the philanthropy “answer” is less readily available to publicly funded and non-elite institutions, whose endowments have grown at a considerably slower pace than those at elite private and top-tier research institutions.

Concluding thoughts

A widely held belief among university faculty and administrators is that the contract between federal funders and universities has changed dramatically in the past sixty-five years. Initially federal agencies fostered research by providing funds for equipment, supplies and facilities, and investing in future researchers through the provision of fellowships and training grants. Summer salaries were allowed as a legitimate research expense, but support for academic-year salaries was not common and was resisted. But very early on, in the 1950s, the system began to change. Faculty academic-year salaries began to be written off grants; graduate students and postdocs increasingly were supported on assistantships on faculty grants and less on fellowships and training grants. In the process, graduate programs became less about training future researchers and more about getting the research done now.

Yes, the contract changed. But a careful reading of the record suggests that the change was orchestrated more by universities than by the federal government. Bush established a funding system that faculty and university administrators were adroit at adapting to their ends. The modern university research system evolved. Many of the stresses that the system now faces are a result of these adaptations. We are reaping not so much what Bush sowed but what universities and faculty pressed to put in place in the 1950s and 1960s in response to *The Endless Frontier* and the opportunities it offered. Some of Bush's key insights regarding research and the research process got lost in the process of adaptation. To name but three: the importance of funding and conducting risky research at universities; the focus on fellowships as a method of supporting graduate students; and, implicitly, the need to strike a balance between support of the medical sciences and other fields of science and engineering.

Many of the stresses on the university research system result from a fixation on the part of universities with increased funding for research. Yet, as the doubling of the NIH budget so aptly shows, increased funding does not address problems that are structural and that are reinforced by positive feedbacks. As we move forward, the time may have come, as Princeton's Shirley Tilghman says, "to have a conversation between the government and the research universities on how to live at steady state" (Mervis, 2013, p. 1935). Such a conversation is unlikely to take place, however. The steady state that Bush had envisioned has long been eclipsed by an addiction on the part of universities to growth for growth's sake. This may be the biggest threat to the health of the university research system.

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Appendix Tables and Figures

A.1 Public Health Service Research Grants (NIH) in Aid, 1948

Institution	Amount (1000s current dollars)	Number of Projects	Percent of total
Columbia University	428,000	37	5.26
Johns Hopkins University	402,000	36	4.96
New York University	320,000	26	3.95
Harvard	315,000	21	3.89
University of Minnesota	310,000	29	3.82
University of California	297,000	29	3.66
University of Chicago	284,000	20	3.5
University of Michigan	209,000	20	2.58
Washington University	191,000	20	2.35
Memorial Hospital, NYC	189,000	12	2.33

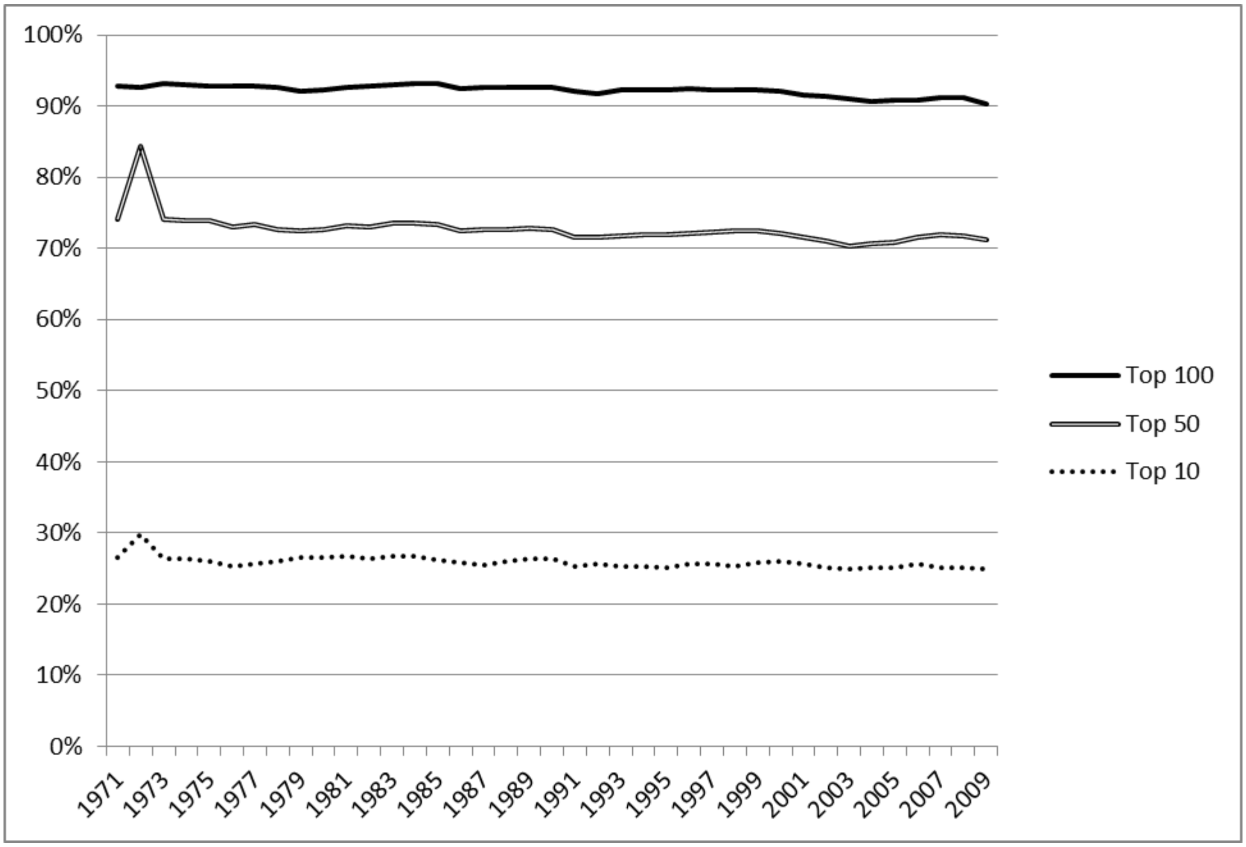
Source: http://history.nih.gov/research/downloads/PHSResearchGrantsinAID-June30th1948.pdf

Table A.2 NSF Awards FY1953

Institution	Amount ($1000 current dollars)	Number of Awards	Percent of Award dollars
Harvard	108.2	6	6.5
Yale	105.1	8	6.3
Berkeley	95.1	8	5.7
Minnesota	77.7	4	4.6
Chicago	73.8	6	4.4
Illinois	54.3	7	3.2
Pennsylvania	51.3	6	3.1
Iowa	49.3	4	2.9
Indiana	58.5	3	2.9
Northwestern	40.0	4	2.4

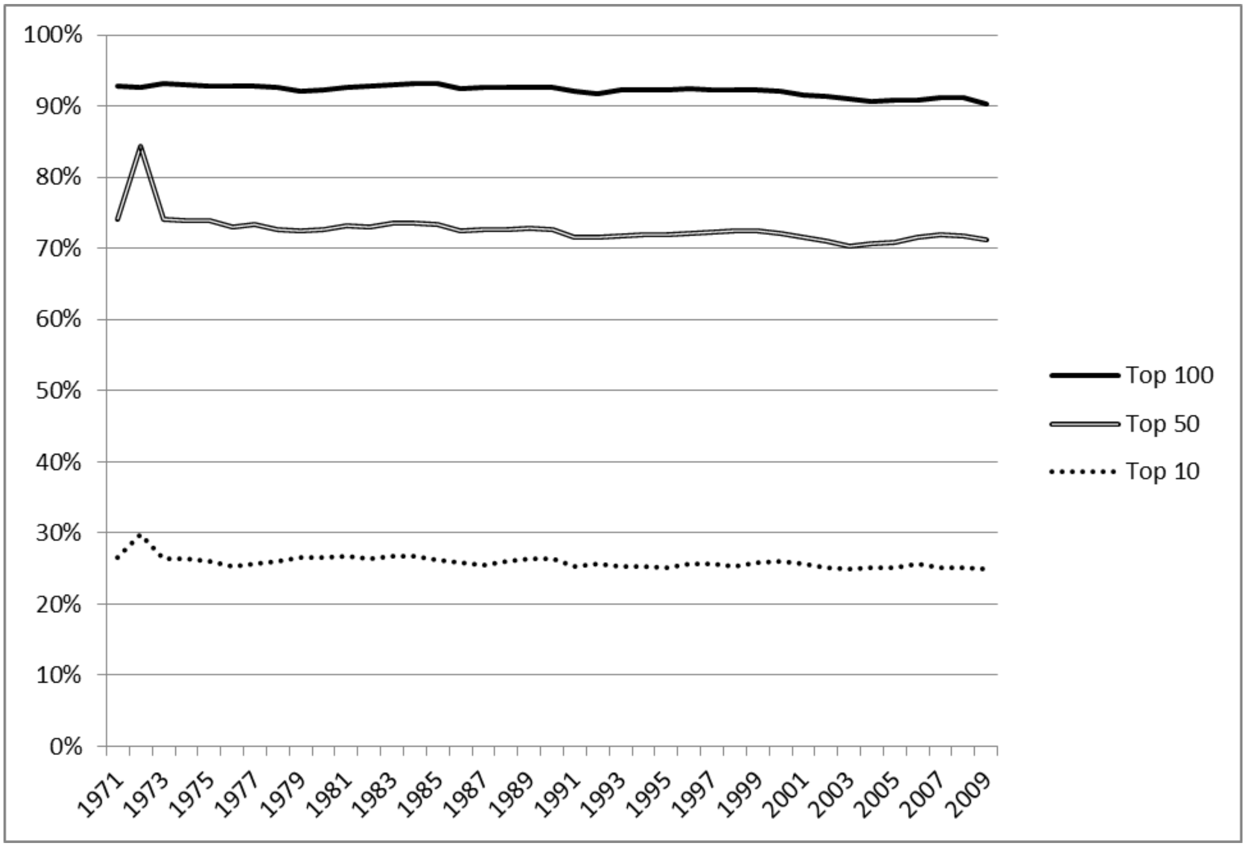
Source: NSF provided data

Figure A.1 Share of NSF Funding



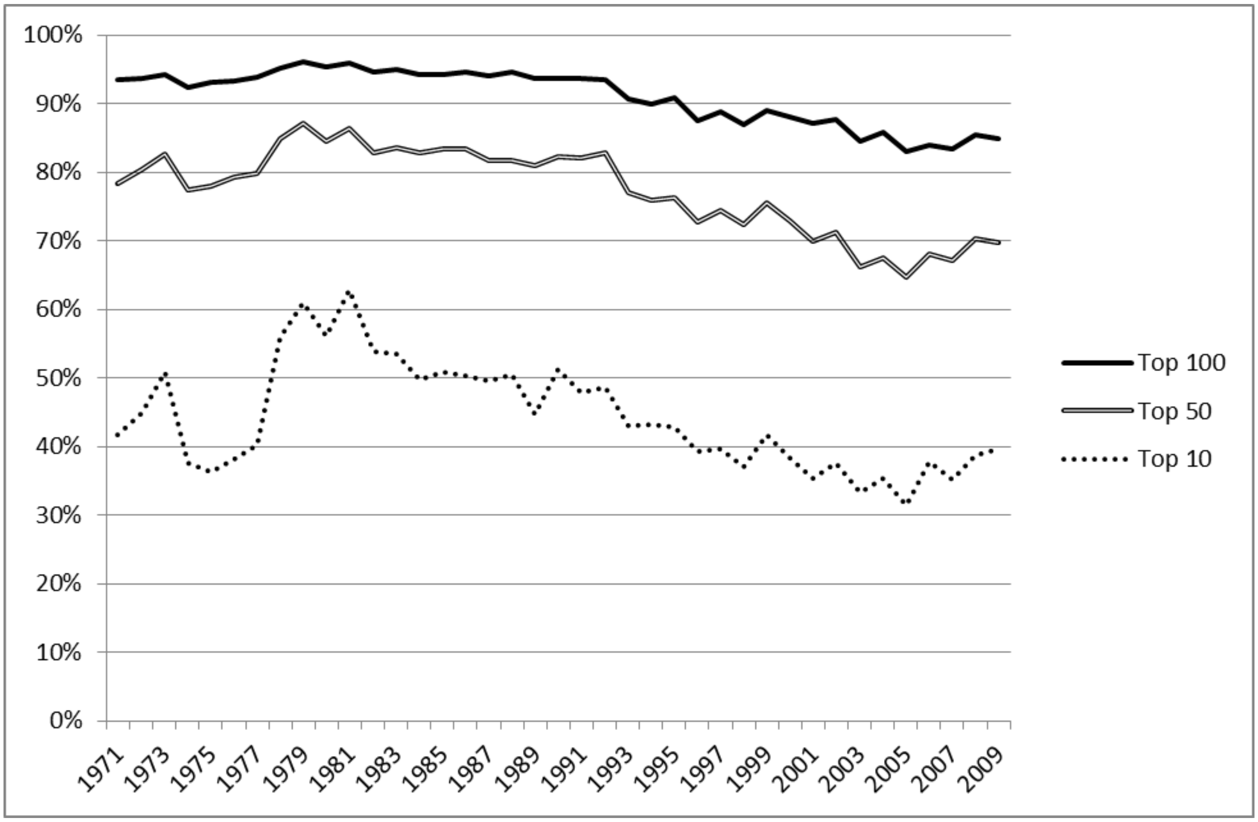
Source: NSF Webcaspar

Figure A.2 Share of NIH Funding



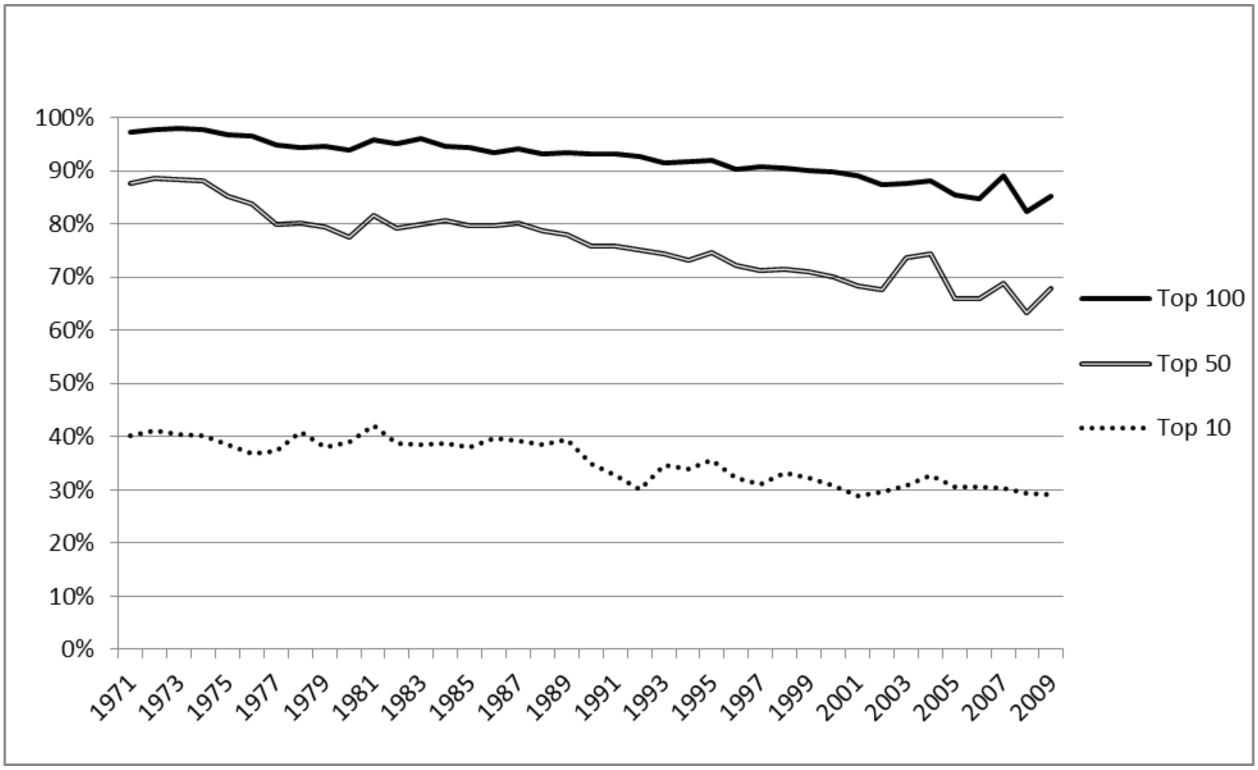
Source: NSF Webcaspar

Figure A.3 Share of DOD Funding



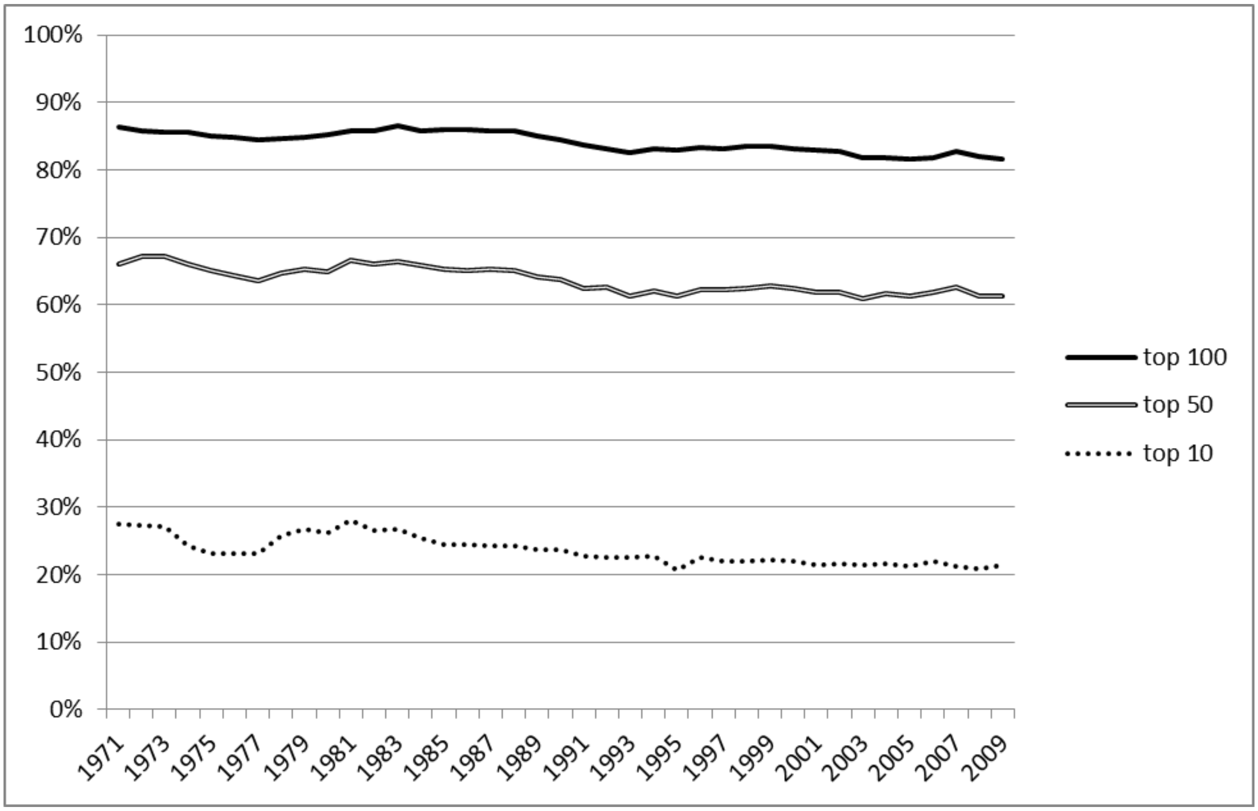
Source: NSF Webcaspar

Figure A.4 Share of DOE Funding



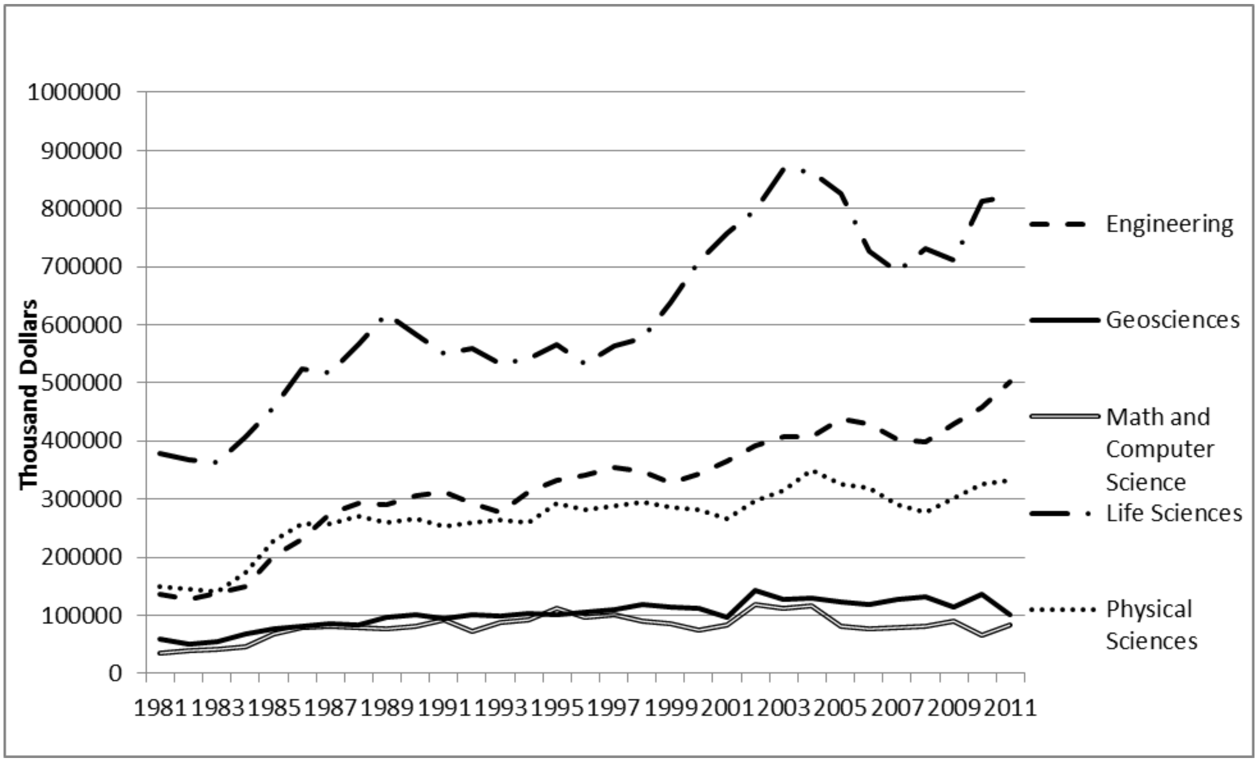
Source: NSF Webcaspar

Figure A.5 Share of Federal R&D Expenditures



Source: NSF Webcaspar

Figure A.6 Real Equipment Expenditures by Field



Source: NSF Webcaspar