The Endless Frontier: Reaping What Bush Sowed?

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Abstract

This paper examines and documents how the *Endless Frontier* changed the research landscape at universities and the response of universities to the initiative. We find that the agencies it established 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 began to push for more resources from the federal government for research, support for faculty salary and research assistants and 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.

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1. Introduction

Science emerged from World War II triumphant. Its contributions to the war effort included the Manhattan project, radar, DDT, and penicillin, thanks in part to which the death rate for all diseases in the Army was reduced from 14.1 per thousand in WWI to 0.6 per thousand in WWII (Bush, 1945). Beyond penicillin, science had contributed breakthroughs in gamma globulin, adrenal steroids, cortisone and blood plasma (Strickland, 1989). 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 from the White House and in the late fall of 1944 Bush set about writing what was to bear the name: *Science the Endless Frontier*. [1]

The report, which was issued in July of 1945, recommended a three-pronged course of action for the federal government.[2] 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."[3] 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

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[1] The title of the report comes from a statement in the president's request letter: "New frontiers of the mind are before us, and if they are pioneered with the same vision, boldness, and drive with which we have waged this war we can create a fuller and more fruitful employment and a fuller and more fruitful life" (Roosevelt, 1945). For a discussion of how Bush maneuvered the president into requesting the report, see a history of NSF prepared by George Mazuzan, http://www.nsf.gov/pubs/stis1994/nsf8816/nsf8816.txt.

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

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

faculty and staff. In the process, the research environment at universities underwent substantial change.

The goal of this paper is to outline how the *Endless Frontier* changed the research landscape at universities and the response of universities to the initiative. 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 and funded 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 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 their 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 research world of today is one in which faculty function like entrepreneurs, running firms within the university. They routinely spend approximately 40 percent or more of their time on grants administration (Kean, 2006); they staff their labs with graduate students and postdoctoral fellows, paying for them off grants (Black & Stephan, 2010); they coauthor with individuals from within and outside their universities, and they use equipment and materials for their research that were unimaginable at the time that Bush wrote the report.

This paper sets out to examine (a) how the federal-university research interface has evolved and continues to evolve and (b) stresses that have emerged in the system and implications they have for discovery and innovation. 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 from 1960 going forward. Section 5 takes stock of how the university research enterprise has evolved and changed since *The Endless Frontier.* Section 6 examines stresses to the system and ends with some concluding thoughts.

Before commencing, a word about data is in order. Ideally, one would want consistent data over the period of time from 1940 until now. This, alas, is not to be. The only reliable long term data that we have concerns the production of PhD students in S&E from 1920 onward and detailed information on awards from NSF since the first year of its inception, 1952. Data on university funding for research and development are available from 1952 forward, but at the aggregated level. Data are only readily available at the institution level beginning in 1972. Data on equipment and research space are only readily available beginning in the 1980s. To facilitate referring to these various data series, we have assembled a set of data appendices, arranged by topic. Figures and tables in the appendices are referred to throughout this discussion. Throughout the paper, science and engineering (S&E) is defined to include engineering, geosciences, life sciences, math and computer sciences, and the physical sciences.

2. The Scientific Landscape Circa 1940s

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.[4] Reflecting this, PhD production was highly concentrated. Slightly more than two-thirds of all PhDs in science and engineering were awarded by ten of the 55 institutions awarding the degree. [5] 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. The Stanford Medical School was a case in point. Located in San Francisco, it focused almost exclusively on clinical practice, not research (November, 2012).

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 that was 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 in the process of 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, in today's dollars not enough to pay for a minute of the electricity required to run the Large Hadron Collider at CERN, which was 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 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 A.2 and (National Academy of Sciences, 1978, p. 95)). PhD production in science and engineering had grown steadily during the 1930s, going from 895 in 1930 to 1379 in 1939 (Figure A.1). By 1940, the number of degrees awarded in science and engineering was 1618. However, as the war accelerated, 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. A deficit clearly was in the making.

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[4] 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.

[5] Data are for the period 1920-1924, provided by Lori Thurgood. See Table A.1. Data are not readily available by institution for the 1930s or 1940s.

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 had the stated objective of building 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.[6]

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 $450 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).

The implementation of Science *The Endless Frontier* was to be largely the responsibility of two federal agencies: the National Institutes of Health, which predated the report, and a new federal organization for research, referred to in the report as the National Research Foundation. Providing funds to the firmly established NIH proved much easier than establishing the new federal research agency that Bush envisioned and the NIH clearly benefited from the stalled attempts to create the former. A primary opponent of Bush's plan for the agency that he envisioned 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 opened for business.[7]

3. Early Years of the NIH and the NSF

3.1 NIH

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

[7] Kilgore was also in favor of supporting research in the social sciences. See http://www.nsf.gov/pubs/stis1994/nsf8816/nsf8816.txt. The question of the support for the social sciences was not resolved in the legislation. Rather, the legislation provided for support of "other sciences," which left wiggle room for their support but gave them second-rate status.

Although the National Institutes of Health's origins date to the 19th century, the NIH was not formally established until 1930. With the establishment of the National Cancer Institute (NCI) in 1937,[8] investments in health research took a major step forward. Health research became more consolidated when NCI was incorporated into NIH in 1944 under Public Law 410, which provided the legal basis for the various programs now in the NIH (National Institutes of Health, circa 1959). New institutes were formed over time, which eventually led the NIH to change its name from the National Institute of Health to the National Institutes of Health.

The Institute's budget in 1948 of $25 million was 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. As one employee of Heart Lung recounted, "When I went to the Heart Institute in 1948, one of the first jobs that Dr. Van Slyke (the first Director of the National Heart Institute) had me do there was spread knowledge of the NIH programs around the United States, visit the universities and medical schools and talk up the grants program" (Strickland, 1989, p. 37). 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. In 1951, by way of example, NCI explicitly stated two criteria for facilities grants: "One indicated that the funds should go to a few large institutions with well-established medical research programs. The other indicated the aid should go to strengthen smaller institutions with limited research resources" (Strickland, p. 38).

Grants were initially reviewed by sending them out to eminent scientists listed in "Men of Science," or other such sources (National Institutes of Health, circa 1959). But by 1946 the concept of study sections had evolved, and henceforth, peer review was to be organized in study sections. 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, however, 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 their research focus.

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[8] The Act gave NCI the authority not only to conduct intramural research but to "make grants in aid for research projects certified by the Council" and provide funds for training (National Institutes of Health, circa 1959, p. 2).

NIH reporting requirements for grants were minimal, a deliberate decision on the part of the first chief of the NIH Division of Research Grants and Fellowships, Dr. Van Slyke, who had found the quarterly scientific and financial reports of war-time contracts overly burdensome. Instead, Van Slyke settled on requiring short, annual scientific progress reports "in order not to divert the time of the researcher unnecessarily from the actual conduct of research investigation" (Strickland, p. 31). Financial reports were semi-annual, and, in Van Sklye's words, "simple" (Strickland, p. 31).

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 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 this reason (Appel, 2000). While NIH's extramural grants program focused on individual research projects, it also included some funding for facilities, as noted earlier, and for equipment. In the early days, equipment was usually supported on individual researcher grants. However, when James Shannon became director of NIH, the institute began to support large equipment purchases (Strickland, 1989, p. 72).[9]

Grants were heavily concentrated in the early years at a handful of institutions (Table C.1). 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 Wisconsin Madison. Taken together, the top ten institutions in 1948 received slightly more than one-third of all the NIH award funds; the top fifty 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.[10]

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. 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).

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

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[9] 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.

[10] A document dated 1948 lists the names and amounts of 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

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 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 fellowship. Allowances were also provided for dependents, travel and tuition (National Institutes of Health, circa 1959, p. 12).[11] 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

Although the act that established the National Science Foundation was approved by Congress in 1950, the agency did not officially begin awarding grants until 1952. Its mission, to support science, especially basic science, distinguished it from all other federal agencies whose support for science was and remains mission driven.

NSF's initial budget was meager compared to that of NIH's, starting in 1952 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). It should be noted, however, that this figure underestimates the disparity between the two in terms of support for university research. While a goodly portion of NIH funds supported intramural research programs, NSF did not have an intramural research program.

While committed to quality, NSF, like NIH, made an effort to identify "atypically good researchers in underdeveloped institutions" (Appel, 2000, p. 59). NSF also made an effort to support research at liberal arts institutions, influenced by the work of Goodrich and Knapp showing that high quality liberal arts colleges produced a disproportionate number of scientists (Goodrich & Knapp, 1951). In its first year of operation, for example, it made grants to Oberlin, Reed and Smith colleges.

Like NIH, NSF 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, which were populated, according to one historian, 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 small budgets and pent-up demand, by the mid -1950s success rates had grown, with but one exception, to over 50 percent. In 1959 the success rate was 62 percent (Appel, 2000, p. 70).[12] Renewals

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[11] The $48,000 is generous compared to the $39,264 stipend for first year NIH postdoctoral fellows supported on NRSA Kirschstein awards.

[12] These success rates are for the division of Biological and Medical Sciences.

(although NSF did not formally refer to them as such) had significantly higher success rates, always over 80 percent. In one year, success rates for renewals were at 89 percent for one division (Appel, 2000). 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 award had been made (Appel, 2000). NSF also provided funds for the purchase of large instruments, such as electron microscopes and supplies as well as funds for 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 which received 6.9 percent of all the funds, followed by Indiana University, Bloomington, which received 5.2 percent of the funding. 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 C.2).

Consistent with Bush's vision and mission to build capacity, an educational unit was established within NSF as part of the initial NSF Act. The division, officially known as the Division of Scientific Personnel and Education (SPE), oversaw the awarding of 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 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. Indeed, the amount of defense funding going to MIT was sufficient for the physicist Alvin Weinberg (Director of the Oak Ridge National Laboratory at the time) to muse in 1962 that it was increasingly hard to tell "whether the Massachusetts Institute of Technology is a university with many research laboratories appended to it or a clustering of government research labs with a very good university attached to it" (Leslie, p. 14). Unlike the NIH and NSF model, however, whose funds went primarily to individual investigators, DOD funds were directed to interdisciplinary research labs, such as the Lincoln Laboratory at MIT and the Research Laboratory of Electronics at MIT. 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.[13] 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 C.1). 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 research.

4. The University Response to Capacity Building

4.1 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

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[13] See discussion in Hemmenheimer regarding the U.S. response to Sputnik and the arguments for the U.S. to"let" the Soviet Union be the first to launch a satellite (Heppenheimer, 1997).

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 A.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 A.2).

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. While the growth in programs was strong in all fields, it was particularly strong in the life sciences, the physical sciences, and engineering, reflecting in part the availability of support in these fields. The process of democratization continued. 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 67 percent four decades earlier. American higher education was becoming more democratized (Table A.1).

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).

Prior to WWII, the federal government played virtually no role in the support of PhD students. 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 Biological and Medical Sciences (BMS) at NSF supported 985 predoctoral students. This was not an insignificant number. The 985 represents 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. The importance of training grants and fellowships continued to increase during the decade. By 1969, NIH reported supporting 9,500 students in such positions. The vast majority, 93 percent, were supported as trainees; fellowships were rare.[14] 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.

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[14] See Figure 2.1 (Coggeshall & Brown, 1984). Available at http://books.google.com/books?id=wV8rAAAAYAAJ&printsec=frontcover#v=onepage&q&f=false

NSF and NIH were not the only federal agencies supporting graduate students. The Atomic Energy Commission supported a number of research assistants, as did NASA, although the latter had a large training grant program as well. In addition, "other" federal agencies supported approximately 10,600 graduate students in 1966, the great majority of these (63 percent) on research assistantships (National Science Board, 1969). Many of these positions were undoubtedly supported on DOD research contracts. Moreover, the NDEA, established in part in response to Sputnik, provided fellowships for over 5,500 graduate students. Although some of these were in the humanities, the majority were in science and engineering.

The federal government also built capacity by supporting postdoctoral fellows. Although the concept of postdoctoral study dates back to 1919 (Assmus, 1993) support for postdoctoral study before the war was minimal and the postdoctoral positions that did exist were largely supported 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 6050 individuals on postdoctoral fellowships and training grants.[15] NIH supported more postdocs on research grants, although the number supported on faculty research grants cannot be determined. NSF also allowed faculty to pay for postdoctoral salaries on research grants. BMS in 1961, for example, supported 213 postdocs on research grants, or 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 not only supporting graduate students on fellowships and training grants to build future research capacity. It was supporting graduate students and postdocs on faculty research grants in order to get the research done now. 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 5.1 in the biological sciences to 5.1 and 5.3 respectively between 1958 and 1964.[16] If Vannavar Bush's three-year degree is at all representative, time to degree had grown considerably since the 1930s. The observation is consistent with the 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 proposals submitted to NIH grew as well. Between 1956 and 1960 the number of competing research project applications received by study sections went from 2750 to 7975; the

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[15] 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),

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

number of study sections increased from 21 to 33 (Divison of Research Grants, 1996). Not surprisingly, success rates began to decline (Table B.1). The increase in submissions continued to grow. In 1987, for example, the Division of Research Grants at NIH received 33,804 proposals; approximately 23,000 were reviewed in one of NIH 67 study sections (Strickland, 1989, p. 86). The number of institutions receiving awards grew as well. While 75 universities and colleges were awarded NSF grants in 1953, by 1971, the number stood at 314 (Figure C.3). The number of institutions supported by NIH grew as well, going from 120 in 1948 to 330 in 1971, the first year for which data are readily available (Figure C.2). Grants became less concentrated as measured by the percent of funds that top institutions received. At NSF the percent going to the top 10 fell from 42 percent in 1953 to the low 30's in the early 1970s. At NIH it went from 36.3 percent in 1948 to the mid-20s (Figure C.2). DOD funds, which were highly concentrated among just three institutions in the late 1940s, were more evenly spread by 1971. The top 10 institutions received 41.7 percent of the research funds; overall, 244 institutions received contracts or grants (Figure C.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).[17] Included were federal support for salaries of new hires (allowing universities to make long term commitments), increased indirect rates on grants[18] 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.

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 (SDP) with the goal of creating additional "centers of excellence." Later in the decade, it changed its goal to providing support to programs that

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

[18] To be more specific, the committee repeated the recommendation of an earlier report (*Strengthening American Science,* p. 34) that "Government departments and agencies concerned should uniformly modify the grant and contract provisions to permit universities and non-profit research institutions to charge full cost of research performed for the government—including overhead—and to amortize capital expenditures as an allowable cost" (The President's Scientific Advisory Committee, 1960, p. 29).

already showed some existing strengths (Appel, 2000, p. 174). Over a nine year period, NSF spent $233 million on 102 institutions.[19] Other agencies also supported "upgrading" 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).

Although government agencies resisted providing long term funds to universities in support of salaries, federal agencies became increasingly more sympathetic to the request that grants cover salary for the time faculty spent on funded research. 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. 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 wholly responsible for raising his own salary."[20] 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).[21] Some university as well as 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.

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

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[19] The majority of the SDP funds were spent at 31 universities that received average awards of $6 million (Appel, 2000, p. 174).

[20] 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; Vence, 2011).

[21] The PSAC report also expressed the concern that paying for salary on grants could lead to the redistribution of income.

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. 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 were, although expensive, 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.

4.2 The 1970s

University administrators associated with the Seaborg report acknowledged that universities would be in an extremely difficult position if the federal government were to back away from its support for research. But they dismissed the possibility. Reflecting on the possibility, George Beadle, Chairman of the Division of Biology at Caltech, acting dean of the faculty at the time, and a member of the President's Scientific Advisory Committee, wrote: "The question is often raised, is it wise for a private institution like Caltech to become so dependent on government? What if the funds should be suddenly cut off or drastically reduced? Clearly we'd be in a bad way. But this will not and cannot happen short of a complete economic collapse of the nation. And in that case all institutions, private and state, would collapse too" (Beadle, 1960, p. 13). Yet only eight years after the report had been issued, universities were to find themselves in a precarious position. While federal funds were neither cut off nor drastically reduced, the brakes were put on and they remained virtually flat in real terms for almost a decade (Figure C.1). Indeed, between 1968 and 1972, real federal expenditures for university R&D declined by 6 percent. Over the 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 science had ended.[22]

University research was sustained in large part because funding from other sectors grew during the period. 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

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

that NIH supported, both at the predoctoral and postdoctoral level, fell by almost one-quarter.[23] Not surprisingly, PhD enrollments declined[24] 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. 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 .6 to .8 years depending upon broad field, reflecting, perhaps, the shift from training grants and fellowships to graduate research assistantships (Table A.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. The exception was physics, where the number of institutions offering PhD degrees grew but by 11 percent (see Table A.2). 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 (Table B.1). The concentration of NIH grants remained virtually unchanged. The HHI measure of concentration for the period, for example, varied by at most by 5 percent (Table C.3).[25] Measured in terms of shares, that received by the top ten universities remained, with but one exception, constant throughout the decade at around 27 percent. The top fifty institutions saw their share decline ever so slightly; the top 100's share stayed virtually the same. The number of universities and medical schools receiving funding stayed almost constant as well, just shy of 300 (Figure C.2).

Things played out somewhat differently at NSF, where the number of institutions receiving grants grew considerably, especially during the late 1970s (Figure C.3). Resources became less concentrated, as well. 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; the share going to the top fifty institutions declined as well, as did the share going to the top one hundred institutions.

At DOD, funds were considerably more concentrated, and patterns were considerably more sporadic, reflecting both "lumpy" contracts and stop-and-go funding (Figure C.4). 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 (Table C.3). The share that the top ten institutions received stayed above 35 percent

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[23] NIH supported 16,000 training grants in 1969. In the early 1970s, 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).

[24] 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).

[25] The HHI stands for the Herfindahl–Hirschman Index, a commonly accepted measure of concentration. It 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

throughout the period and at times exceeded 60 percent; the share received by the top fifty and the top one hundred remained reasonably stable as well, as did the number of institutions receiving contracts or grants from DOD.

DOE was yet a different story (Figure C.5). Although the number of universities receiving funds increased during the latter 1970s, DOE funded fewer universities than did the other three agencies. 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 (Table C.3).

4.3 The 1980s-1998

The relative importance of federal funding for university research continued to decline during the 1980s and most of the 1990s. This time it was not because the Federal government's expenditures for university research were flat, however, but rather the case 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 times during the period, and universities themselves, whose contributions to their own research grew by 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 C.1).

The number of universities and colleges receiving research contracts and grants from Federal agencies rose during the 1980s, especially the number receiving DOD, DOE, and NSF funds (Figures C.3, C.4, C.5). The number receiving NIH funds, which had remained remarkably constant for many years, finally began to increase (Figure C.2). The concentration of resources, as measured by the HHI index and the percent received by top institutions continued to decline for all agencies, save NIH where it stayed constant (Table C.3 and Figures C.2, C.3, C.4, C.5, C.6).

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 (Figure A.1).

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 A.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 A.3). The ratio of graduate students supported as research assistants to those supported on training grants and fellowships grew from 3.35 in the physical sciences in 1979 to 4.25 in 1994; in engineering it went from 2.90 to 4.02 during the same period; in the life sciences it grew from 1.21 to 1.55 (Table A.4).

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 G.1). By 2001, however, with the demise of the dot.com bubble, the career prospects of newly trained engineers and physicists had deteriorated considerably. 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 (Figures G.1 and G.2). The number of postdocs almost doubled between the early 1980s and the late 1990s (Figure F.1).

Definite commitments for new PhDs in the biological sciences also deteriorated during the early 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.[26]

There were a number of disturbing trends. Time to degree had increased, the percentage of life scientists holding postdoctoral positions had grown, and the duration of the postdoc position had also increased. Moreover, the likelihood that a young life scientist would hold a tenure-track position, especially at a research university, had declined. Furthermore, young faculty were experiencing increasing difficulty getting NIH grants funded and were getting funded for the first time at later and later ages. Between 1980 and 1996, for example, the age at first award had grown from slightly less than 36 to almost 40.[27]

After documenting and studying these trends, the committee made four recommendations: (1) restraint in the growth of the number of graduate students in the life sciences, (2) dissemination of accurate information on the career prospects of young life scientists, (3) improvement of the educational experiences of graduate students, and (4) enhancement of opportunities for independence of postdoctoral fellows. In a fifth recommendation, the committee conveyed the conviction that “the PhD degree [should] remain a research-intensive degree, with the current primary purpose of training future independent scientists” (National Research Council, 1998, p. 8). In other words, the committee did not endorse the idea of training PhDs in the life sciences who would then pursue alternative careers.

The university community—especially those in the biomedical sciences—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 the levers that could influence these incentives—such as

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[26] Henry Riecken, who was the Boyer Professor Emeritus of Behavioral Sciences at the School of Medicine of the University of Pennsylvania, initially co-chaired the committee. Riecken, however, did not fully support the recommendation of the committee regarding training grants and eventually resigned as co-chair and wrote an “alternative opinion.”

[27] The figures are for PhDs. See http://nexus.od.nih.gov/all/2012/02/03/our-commitment-to-supporting-the-next-generation/

the requirement that the metrics for evaluating a faculty's grant include information on the career outcomes of those trained in his or her lab.

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 out of their own funds (Figure H.1); 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. But the problem 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. The end result was that the average indirect rate at private research and doctoral universities, which was over 60 percent in 1983, fell to about 55 percent in 1997 and has remained fairly constant since (Stephan, 2012, p. 122). Rates at public institutions average about 10 percentage points lower. According to a 2000 Rand report, universities, at these rates, "recover between 70 to 90 percent of the facilities and administrative expenses associated with federal projects" (Goldman, Williams, Adamson, & Rosenblat, 2000, p. 33)

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.[28] Not only do such packages play an important role in recruiting senior faculty, they also provide the time and the resources that newly minted faculty need to develop the preliminary results to place them in a competitive position for receiving grants. Start-up packages contain 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 to new hires in the last several years; in one-half of the start-up packages they represent between 25 and 40 percent.[29]

Start-up packages can be quite large. A 2003 survey, for example, found the average of the mean start-up packages offered by institutions for an assistant professor in chemistry was $489,000; in biology, it was $403,071.[30] 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

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[28] Ehrenberg argues that a third factor also has led to increased contributions of universities towards research and that is the growing requirements of federal agencies that universities provide matching funds in grant proposals (Ehrenberg, 2012).

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

[30] 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).

and $1,178,000 between FY08 and FY10 for assistant professors in biochemistry and biology.[31] Those in chemistry for the same period were between $535,000 and $635,000. Start-up funds for an associate professor of chemistry were $1,178,000. Start-up packages can be considerably higher at medical schools. A full professor reportedly can receive a package of $5 million or more.

No one has done the accounting regarding where universities draw these institutional funds for research 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. Their research also shows that institutions that increase the size of their graduate student enrollments compensate by increasing tuition. This is true for both public and private 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 H.2. 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 H.3 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.[32] 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 1 and Doctoral II.

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

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[31] 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.

[32] The ratio is computed for institutions reporting in that year a positive R&D expenditure value.

are also 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 expenditures for research equipment. As can readily be seen from Figure D.1, the amount that universities spend on equipment for research—either out of their own funds or the funds provided by others has been growing; it almost doubled in the six-year period between 1984 and 1990 and almost doubled again in the 1990s. Growth in equipment expenditures was most striking in the life sciences, engineering and the physical sciences (Figure D.2). Expenditures for equipment grew at a slower pace in the geosciences and in math and computer sciences. Concomitantly, expenditures for equipment became less concentrated among Research I universities (Figure D.1).

In terms of level, expenditures for equipment are the greatest in the life sciences, reflecting strong funding, followed by engineering and the physical sciences. In terms of share of equipment expenditures, that for the life sciences ranged from 40 to 50 percent during the period; that for the physical sciences hovered around 20 percent, while the share of equipment expenditures made by engineering increased from 20 to around 25 percent (Figure D.3).

Equipment intensity also varies considerably by field. Not surprisingly, the physical sciences typically spend the largest portion of their research budgets on equipment—anywhere from 8 to 10 percent. The life sciences, which range from 5 percent to 2.5 percent, spend the least (Figure D.4).

Faculty and administrators often express the common 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 D.4 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 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, the membership fee that universities pay to belong to SER-CAT and thus be able to use synchtron beamtime at the Argonne National Lab to determine protein structure costs approximately $250,000.[33] Yet the synchrotron beamline built at Argonne cost approximately $7 million to construct. Neither of these costs is likely to show up in the university R&D expenditure accounts for equipment.

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[33] SER-CAT stands for the Southeast Regional Collaborative Access Team, a consortium formed in the late 1990s to build out a sector of the Advanced Photon Source at the Argonne National Laboratory (Stephan, How Economics Shapes Science, 2012, pp. 93-95)

4.4 NIH doubling and years following the doubling

In 1998 President Clinton, in his State of the Union Message, proposed a significant increase in funding for NIH. Congress complied and, between 1998 and 2003, the NIH budget doubled in nominal terms. 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 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 (Table B.1). 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.[34] 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 G.1) and the percent taking postdoctoral positions rose (Figure G.2).

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 E.1).

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 (Table B.1). One reason for the decline in success rates was the substantial growth in budgets accompanying the 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.

Some of the new grants during the doubling went to researchers who had heretofore not received NIH 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

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[34] 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).

percent to 29 percent. The number of first-time investigators grew by less than 10 percent during the doubling. 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 (Figure F.2). PhD production grew by almost 38 percent (Figure A.2).

5.0 Taking Stock

Looking back from our 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. They have 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 AAU puts considerable emphasis on federal funds, as do the Carnegie Classifications. 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 arguably more than 100. 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 C.6). 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; that going to the top fifty and top one hundred has decreased as well. The HHI index, which has always been relatively low, with minor exceptions for DOD funding, has declined by about 30 percent. 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 six 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 A.1) as has the percent awarded by Research I institutions (Figure A.3).

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. At the individual university level, this takes the form of hiring lobbyists to work on the university's behalf to direct federal (and state) funds to the university.[35] At the group level, it is done by issuing 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 only last year 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 changed dramatically 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 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.[36] 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. Many 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.

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

[36] Every year since 1990 Congress has legislatively mandated a provision limiting the direct salary that an individual may receive under an NIH grant. For FY2012 Congress restricted the amount of direct salary to Executive Level II of the federal Executive Pay scale. The Executive Level II salary is $179,700. This is a reduction from the 2011 level of $199,700 which was tied to Executive Level I salary, and is the first time it has ever been reduced. In 1990 and 1991 the cap was not tied to Executive level pay It was $120,000. It moved very modestly until 1999 when it moved to 136,000. It then increased through the 2000's. See http://grants.nih.gov/grants/policy/salcap_summary.htm

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."[37] 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 (see Figure E.1). 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.

Another reason faculty are employing more graduate students and postdocs to work in their labs is that increasingly their own time is required for administrative functions. Reporting requirements and the administrative time associated with grants have grown dramatically since the early days of NIH when reports were short and annual "in order not to divert the time of the researcher unnecessarily from the actual conduct of research investigation" (Strickland, 1989, p. 31). Moreover, faculty now spend considerable time complying with federal and state regulations (such as IRB requirements), which have grown over time, as well as time spent writing, submitting and often resubmitting grant proposals. A 2006 survey found that U.S. scientists spend 42 percent of their research time filling out forms and in meetings; tasks split almost evenly between pre-grant (22 percent) and post-grant work (20 percent) (Kean, 2006).

External funding, which was once viewed as a luxury, has become a necessary condition for tenure and promotion. External funding is even more important for faculty on soft money positions or for those whose tenure is uncoupled from financial support. 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 at around 20 percent (Tables B.1 and B.2).

6.0 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 here in this 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

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

universities that may place universities at increased financial risk (5) a flat or declining amount of federal funds for research.

6.1 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 just 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 (Tables B.1 and B.2). One reason for this is that agencies feel pressed to report successful research (Petsko, 2012). Another is that it is easier to justify funding safe bets and to choose among proposals 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, as Azoulay and coauthors point out, 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 who, to quote Stephen Quake, a professor of bioengineering at Stanford University, face"funding or famine" (Quake, 2009). Moreover, the fact that grant renewals have a much higher chance of being positively reviewed, be they formal or de facto, discourages faculty from taking up a new research agenda 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, it is pretty clear that if everyone is risk averse when it comes to research there is little chance that transformative research will occur and 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. “Statistically it is certain that important and highly useful discoveries will result from some fraction of the undertakings in basic science; but the results of any one particular investigation cannot be predicted with accuracy” (Bush, 1945, p. 17). In Bush’s view, 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 this, placing pressure on faculty for quick, predictable, results. Finally, and more generally, one 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).

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

A primary rationale 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 and training grants.

It did not take long, however, 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 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 lowly graduate students, began increasingly to resemble a pyramid scheme. In order to staff their labs, faculty recruited PhD students into their graduate programs, providing them tuition and a research assistantship and the implicit assurance of interesting research careers. Upon receiving their degree, it became mandatory in many fields for students who aspire to a faculty position to first take an appointment as a postdoc.

The pyramid scheme works as long as the number of jobs grows quickly enough to absorb the newly trained. Yet by most indications, the system that has evolved is producing more PhDs than the market for research positions demands given current levels of funding for research. Demand is based on the need to staff labs now. Not upon demand for future researchers. While in certain fields, such as engineering and the physical sciences, a substantial component of this is cyclical, in the field of the biomedical sciences it is arguably 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 (Figure G.3).

This model for staffing labs has inefficiencies 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 (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. 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. [38]

6.3 Overexpansion of research facilities

In recent years, universities have gone on a building binge, constructing a substantial amount of new research space. Indeed, between 2001 and 2011, net assignable square feet for research increased at universities and medical schools by 30 percent. As seen in Figure E.1, 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. Some of this space has been paid for by private philanthropy. For example, at MIT, David Koch contributed $50 million to the construction of an institute for cancer research that bears his

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[38] Why smart young people put up with such a system relates to several factors. 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, and one factor in particular is a taste for science, for finding things out. 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 all-too-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. Their lifeblood depends on recruiting new talent to staff their labs. There is a moral hazard here: faculty lack the incentive to provide straightforward information regarding job outcomes—and they don't. To quote David Levitte, a professor of physiology, University of Minnesota: "There is no honesty at all in recruiting PhDs…There's not a hint that there's a shortage of jobs" (Vence, 2011, p. 44). PhD programs, despite recommendations of national committees, have been slow to make placement information available.

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 much of 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 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 unlikely to improve in the near future given the threat of 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.

6.4 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 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. 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. The age distribution of Congress does not hurt. The average age of members of the House of Representatives in 2009 was 56.0; the average age of senators was 61.7. Both chambers were considerably older than they were at their "youngest" in 1981, when the average age in the House was 48.4 and the average age in the Senate was 52.5 (Stephan, 2012, p. 128).

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, as noted above, 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 our 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.

6.5 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 the current threat of 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 (see Figure C.1) 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 and, as the economy picks up, this source is likely to grow. But given past experience, industry is unlikely to substantially increase its share of university R&D.

This leaves only two, related sources: universities themselves and philanthropic organizations and gifts. The first has been discussed above; the second only briefly alluded to. Feldman and coauthors, in recent research, show that 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-Research I 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, sometime 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 faculty grants as research assistants, and less on fellowships and training grants. In the process, graduate programs became in a sense 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 adaptions. 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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Appendices

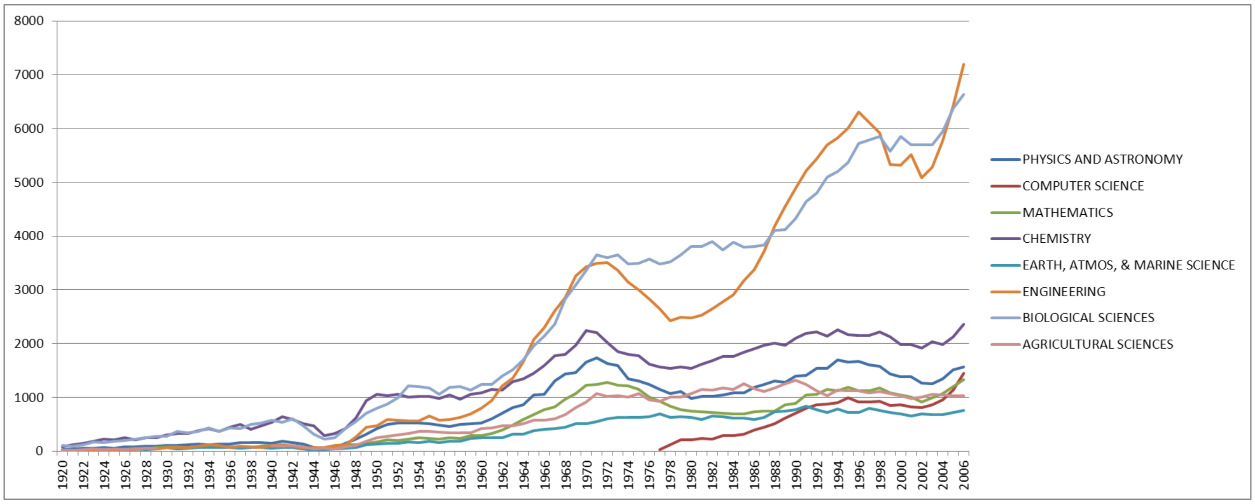
Appendix A: PhD Production

Table A.1 Top-25 Universities Awarding PhDs in Science and Engineering, 1920-1924, 1968, 2011

Name of Institution	Number of PhDs	Name of Institution	Number of PhDs	Name of Institution	Number of PhDs
1920-1924	1920-1924	1968	1968	2011	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-NY	207	Purdue University	300	University of Florida	503
Johns Hopkins University	186	Massachusetts Institute of Technology	292	University of Illinois at Urbana-Champaign	494
Harvard University	152	U. of Michigan at Ann Arbor	282	University of Michigan at Ann Arbor	487
U. of Illinois-Urbana-Champaign	144	Stanford University	274	Purdue University	472
University of Calif-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
Mass Institute of Tech	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 U	143	University of Maryland at College Park	325
U. of Pittsburgh-Pittsburgh	26	Johns Hopkins University	140	Johns Hopkins University	317
Iowa State University	23	Northwestern Univ	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 Univ	288
Total top 10 (percent)	1855		3047		4814
	68.1		27.1		17.12
Total top 25 (percent)	2535		5454		10002
	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	425.78		139.16		82.66

Source: 1920-1924 data, Lori Thurgood, correspondence of unpublished tabulations; 2011 data SED from Webcaspar.

Figure A.1: Number of PhDs Awarded in U.S. by Field in Science and Engineering, 1920-2006



Source: Unpublished NSF records and Webcaspar.

Figure A.2 PhDs Awarded in Science and Engineering 1966-2010

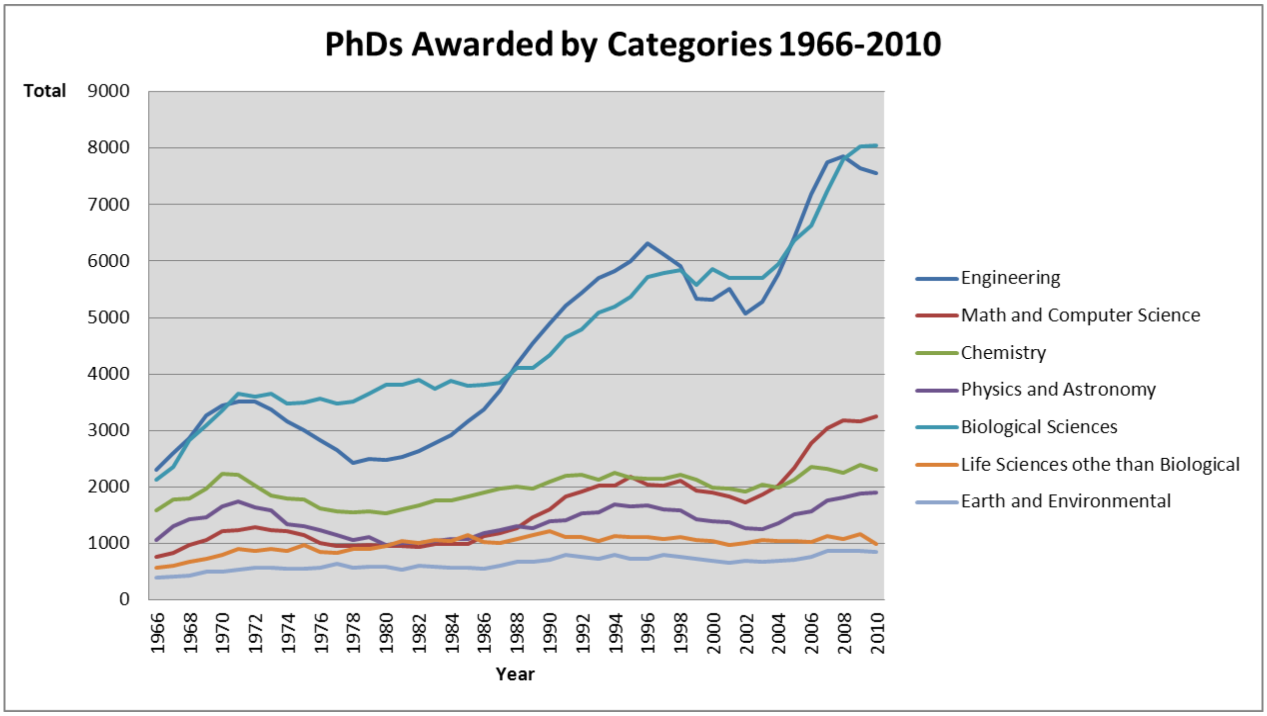


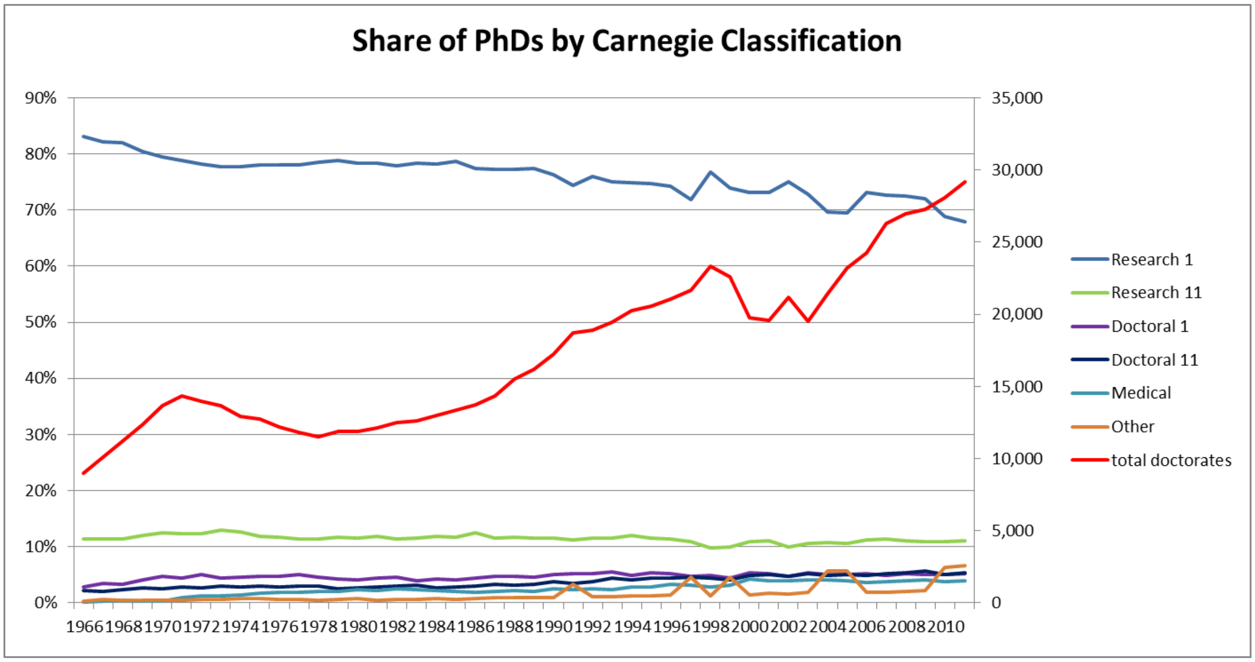
Table A.2

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 Research Council 1978, page 39, Table 39.

Figure A.3 Share of PhDs Awarded in S&E by Carnegie Classification 1966-2010 and Number of Degrees Awarded



Source: Webcaspar, Survey of Earned Doctorates

Table A.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

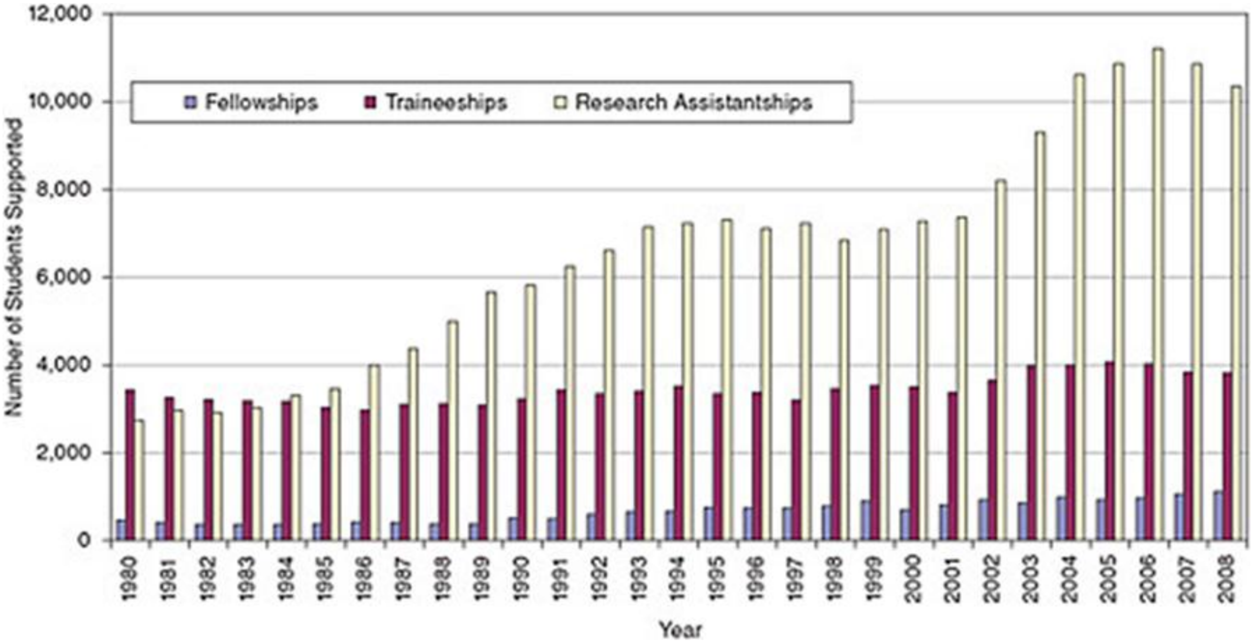
Source: Survey of Earned Doctorates. NSF/NIH/USED/USDA/NEH/NASA Survey of Earned Doctorates, updated data. Source for 1958-1960 is Graduate Education, Parameters for Public Policy, National Science Board 1969, NSB 69-2

Table A.4 Ratio of Graduate Research Assistantships to Training Fellows and Fellowships, Selected Years

Year	Physical Sciences	Engineering	Life Sciences
1979	3.35	2.93	1.21
1984	3.93	2.93	1.16
1989	4.88	4.30	1.46
1994	3.98	4.02	1.55
1999	4.25	4.17	1.47
2004	4.42	4.40	1.78
2009	4.34	4.57	1.90
2011	3.55	4.19	1.97

Source: Webcaspar NIH-NSF Survey of Graduate Students and Postdoctorates in Science and Engineering. Note that 1979 is the first year for which training support was separated from other forms of support. Survey includes students enrolled in masters programs.

Figure A.3 NIH-supported Graduate Students by Fellowship, Traineeship and Research Assistantship



Source: National Research Council. 2011. Research Training in the Biomedical, Behavioral, and Clinical Research Sciences, Washington, DC: National Academies Press, p. 47.

Appendix B. Success Rates NIH and NSF

Table B.1 NIH Success Rates, Various Years

Year	Percent Funded
Mid-1950s	65
1959-1960	Low 50’s
1965	49.6
1970	32.9
1975	44.4
1980	32.6
1985	32.4
1998	31
1999	32
2000	32
2001	32
2002	31
2003	30
2004	25
2005	22
2006	20
2007	21
2008	22
2009	21
2010	21
2011	18
2012	18

Chubin, Daryl and Edward Hackett, Peerless Science, page 26, NIH data book
http://report.nih.gov/NIHDatabook/Charts/Default.aspx?showm=Y&chartId=124&catId=13

Table B.2 NSF Success Rates, Various Years*

Fiscal Year	Rate
1952	23.1
1953	27
1954	39.5
1955	37.8
1956	51.5
1957	49.3
1958	44.4
1959	62.4
1960	57.3
1961	51.0
1962	54.7
1963	53.0
1964	61.2
1965	50.1
1966	56.3
1967	57.1
1968	54.1
1999	32
2000	33
2001	31
2002	30
2003	27

2004	24
2005	23
2006	25
2007	26
2008	25
2009	32
2010	23
2011	22

*Rates for 1952-1968 for the Division of Biological and Medical Sciences; those for 1999 and therafter are for all of NSF. Source: Appel, p. 70 and various Reports to the National Science Board on the NSF's Merit Review Process, various fiscal years.

Appendix C: Funding for University Research

C.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	3.50
University of Michigan	209,000	20	2.58
Washington University	191,000	20	2.35
Memorial Hospital, NYC	189,000	12	2.33

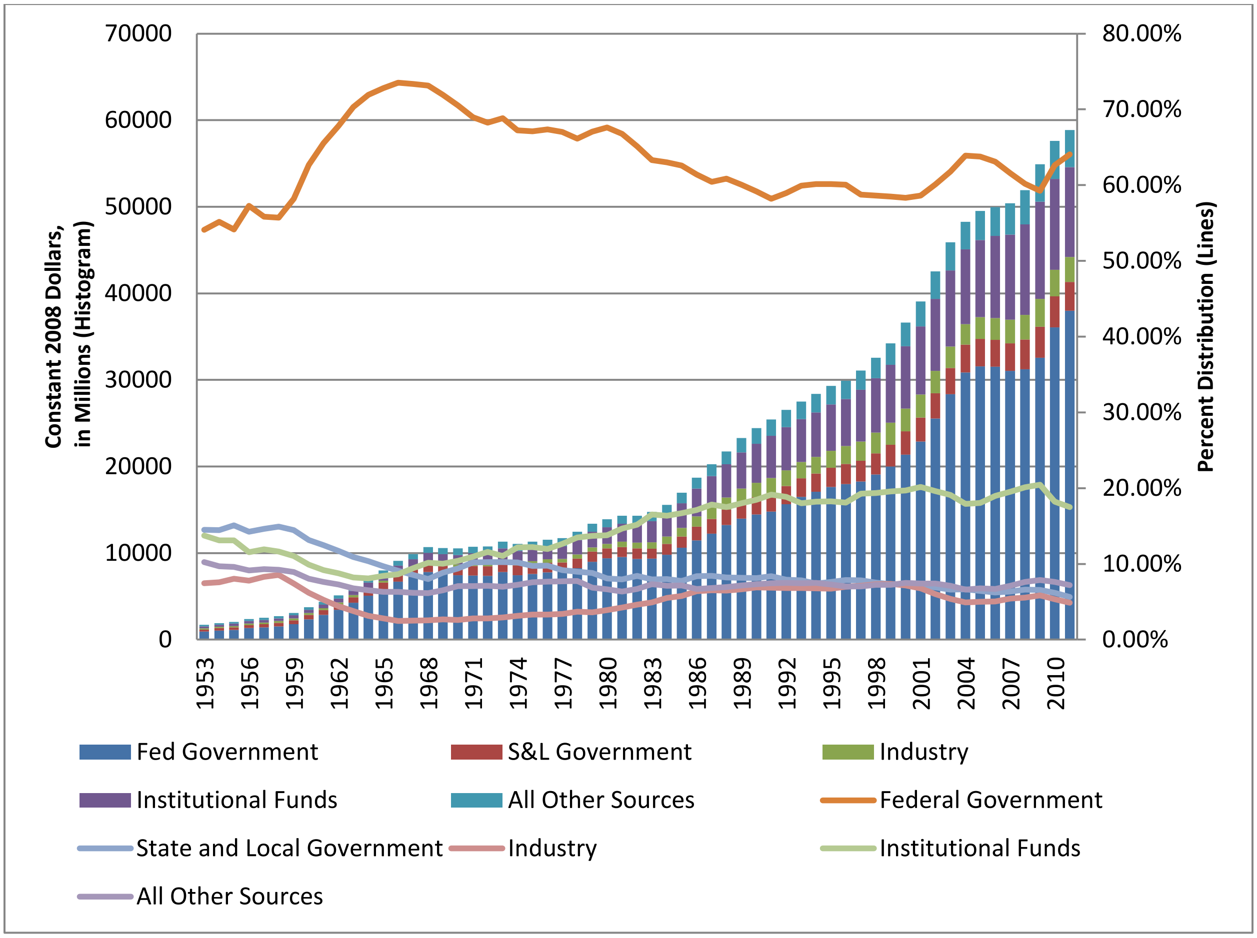
Source: http://history.nih.gov/research/downloads/PHSResearchGrantsinAID-June30th1948.pdf

C.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 C.1 Support for Academic R&D by Sector: 1953-2011



Source: Webcaspar

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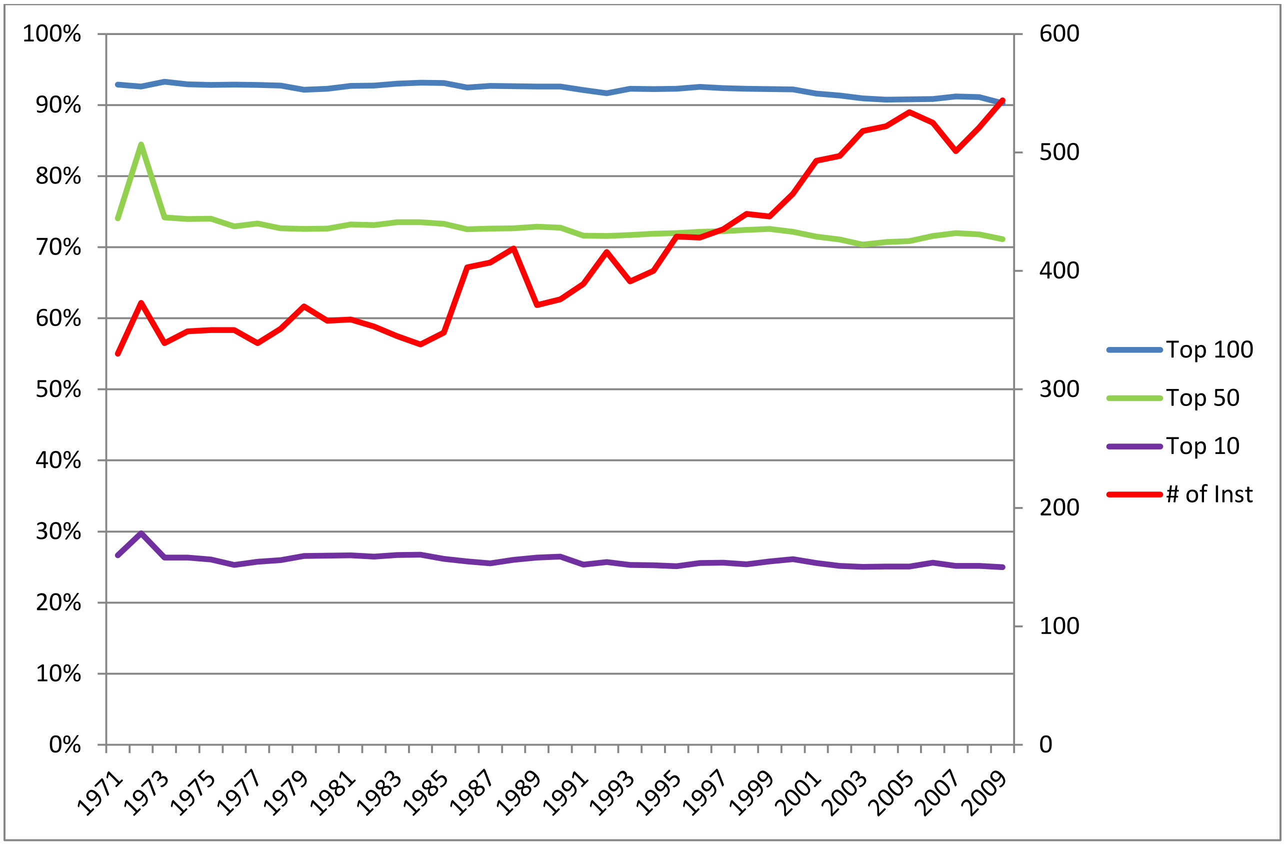
Figure C.2

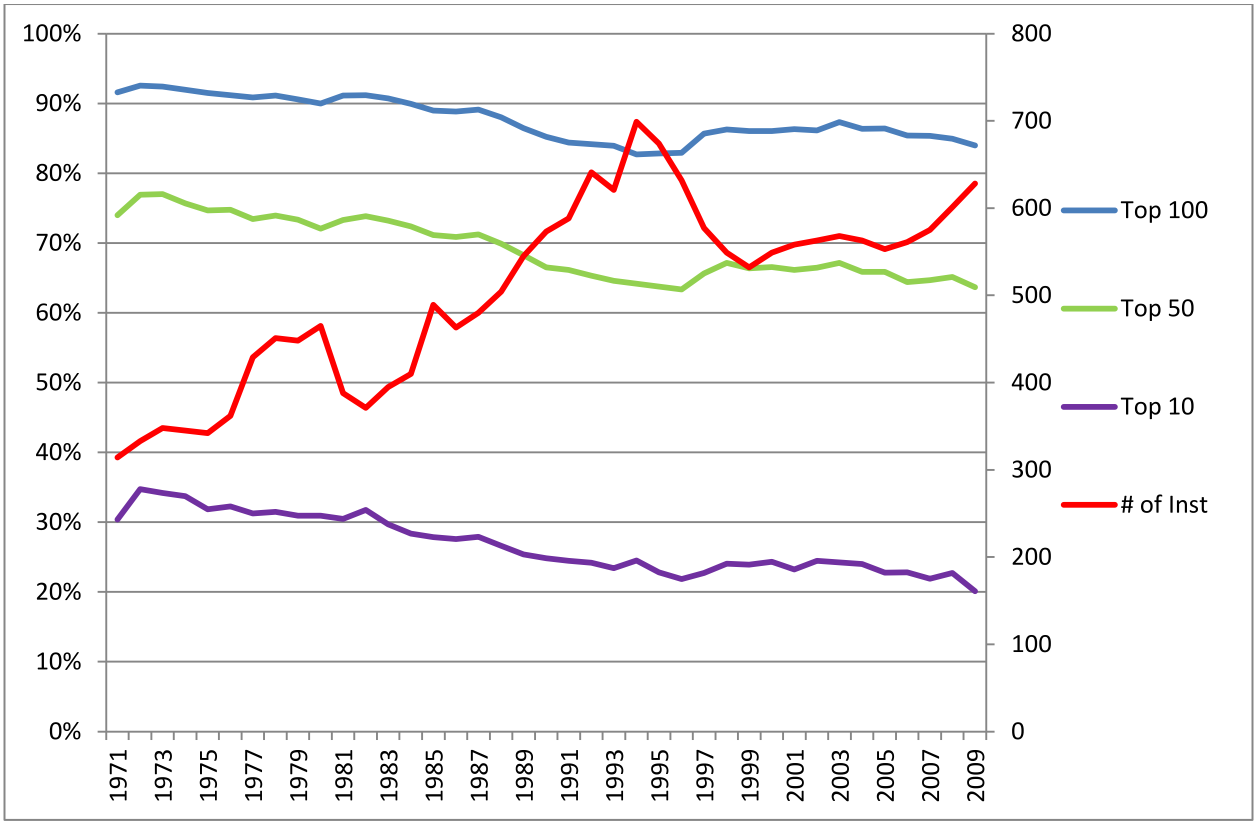
NIH Funding for University Research by Number of Institutions and by Top-10, Top-50 and Top-100, 1971-2009



Source: Webcaspar

Figure C.3

NSF Funding for University Research by Number of Institutions and by Top-10, Top-50 and Top-100



Source: Webcaspar

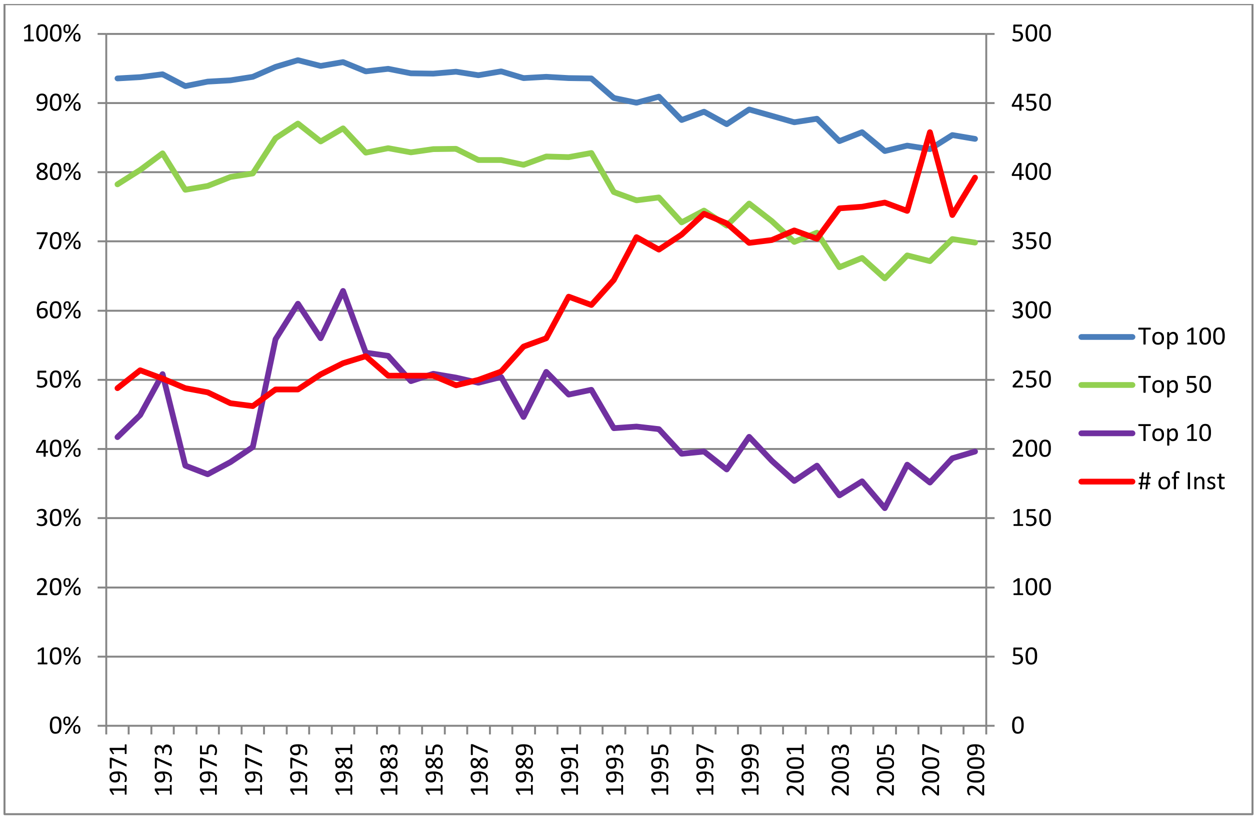
Table C.3 Herfindahl-Hirschman Index (HHI) Measure of R&D University Expenditures, 1971-2009

	HHI				
year	**NIH**	**NSF**	**DOE**	**DOD**	**Fed R&D**
1971	142.99	156.72	250.34	332.11	140.37
1972	139.20	191.20	260.29	484.30	138.95
1973	143.06	184.54	261.59	847.26	140.48
1974	141.58	182.23	257.43	208.07	118.79
1975	141.04	165.13	253.93	202.57	114.59
1976	136.82	176.48	239.89	217.12	113.73
1977	138.81	170.27	302.70	232.89	112.96
1978	138.56	166.41	434.45	1021.32	133.14
1979	140.05	163.40	345.32	1522.55	145.45
1980	140.01	162.18	406.84	971.27	133.89
1981	141.85	157.61	429.43	1666.77	84.96
1982	140.75	165.91	314.45	946.15	145.17
1983	142.85	156.79	318.00	762.61	142.36
1984	143.26	147.14	322.78	557.22	130.10
1985	141.37	142.83	286.97	515.86	124.41
1986	138.67	139.07	298.34	519.03	125.78
1987	138.39	143.06	276.96	550.34	125.42
1988	140.23	134.05	249.98	609.22	127.52
1989	141.88	125.92	259.13	412.04	120.01
1990	142.20	120.41	217.10	601.76	121.64
1991	136.26	118.01	191.69	541.99	115.18
1992	136.54	114.39	181.96	589.36	114.25
1993	137.23	112.78	212.88	445.78	112.27
1994	136.75	116.80	222.66	532.49	115.72
1995	136.80	110.29	243.98	429.39	111.71
1996	138.31	106.28	207.56	369.69	114.49
1997	138.29	114.69	199.48	334.48	111.24
1998	137.22	120.51	212.06	273.57	110.91
1999	138.65	118.22	206.64	431.02	114.80
2000	138.53	119.37	178.20	330.36	110.89
2001	136.10	116.04	163.29	257.97	107.32
2002	133.71	120.17	166.18	295.99	109.53
2003	130.98	121.31	182.28	214.02	105.43
2004	132.12	118.73	205.56	258.51	107.28
2005	131.52	113.42	184.27	216.02	104.52
2006	134.07	111.06	184.32	356.33	109.48
2007	133.86	110.57	180.03	299.28	108.26
2008	135.19	112.29	154.09	323.89	104.51
2009	132.25	103.10	144.73	357.33	106.93

Source: Webcaspar

Figure C.4

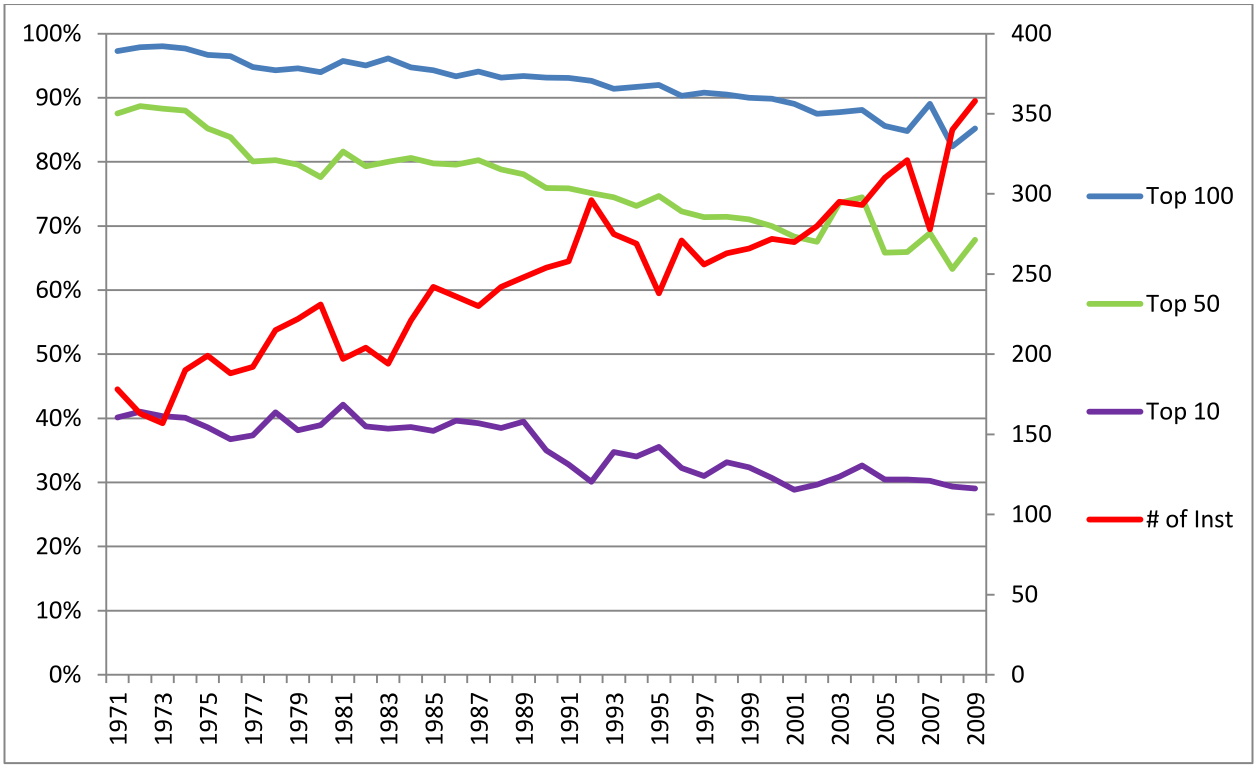
DOD Funding for University Research by Number of Institutions and by Top-10, Top-50 and Top-100



Source: Webcaspar

Figure C.5

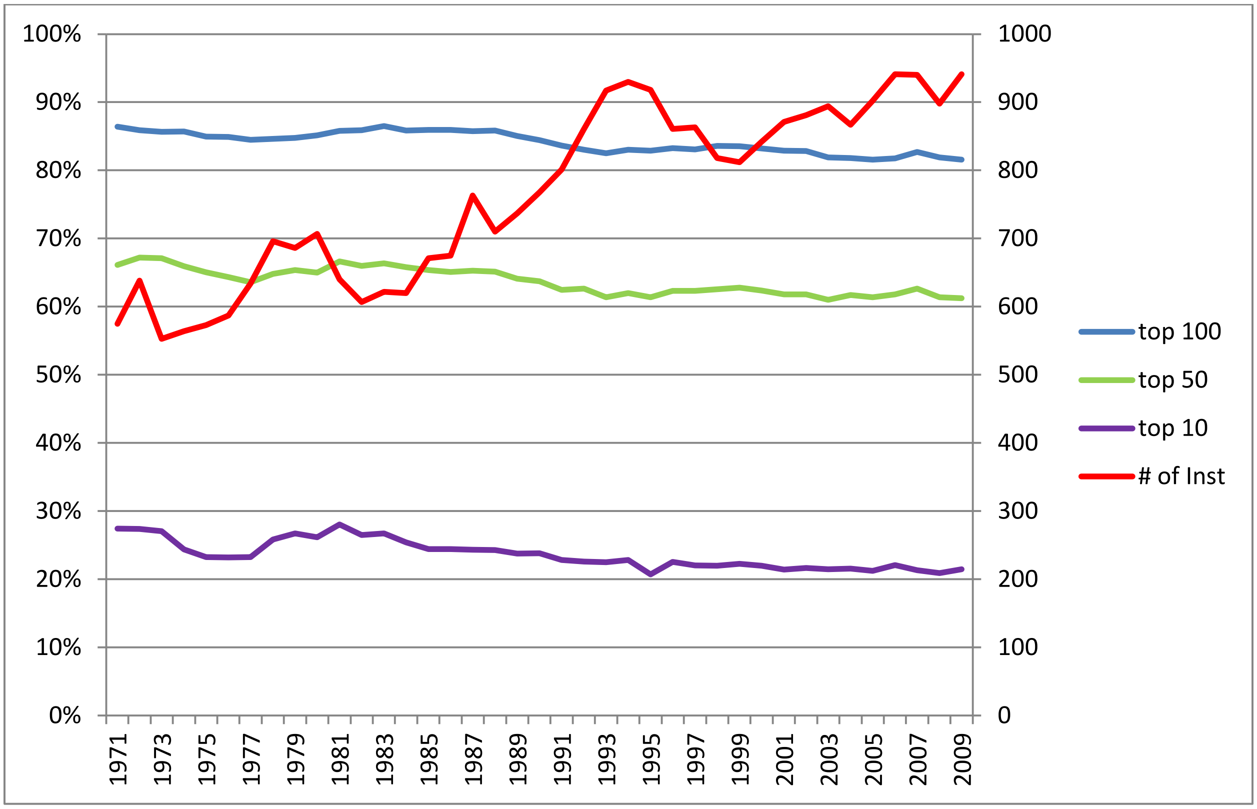
DOE Funding for University Research by Number of Institutions and by Top-10, Top-50 and Top-100



Source: Webcaspar

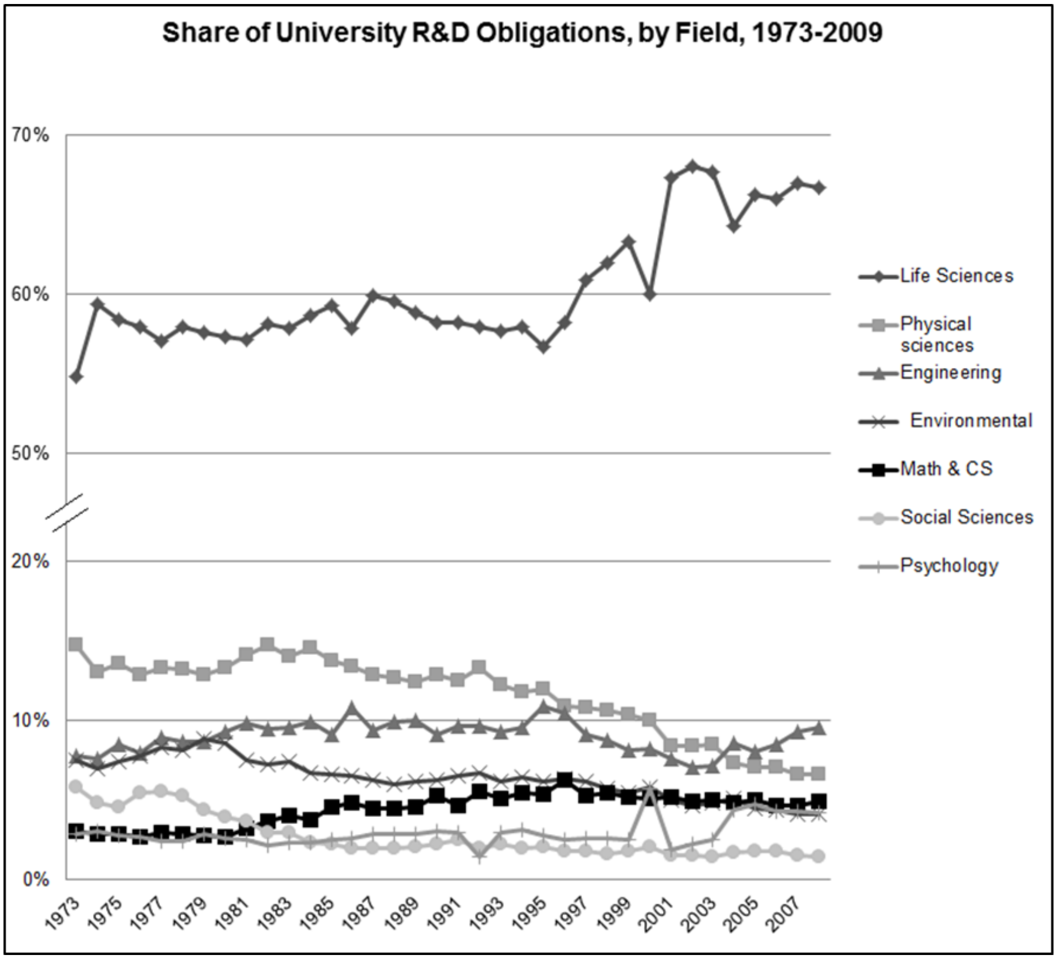
Figure C.6

Total Federal R&D Expenditures for University Research, by Number of Institutions and by Top-10, Top-50 and Top-100



Source: Webcaspar

Figure C.7 Share of University R&D Obligations by Field, 1973-2009

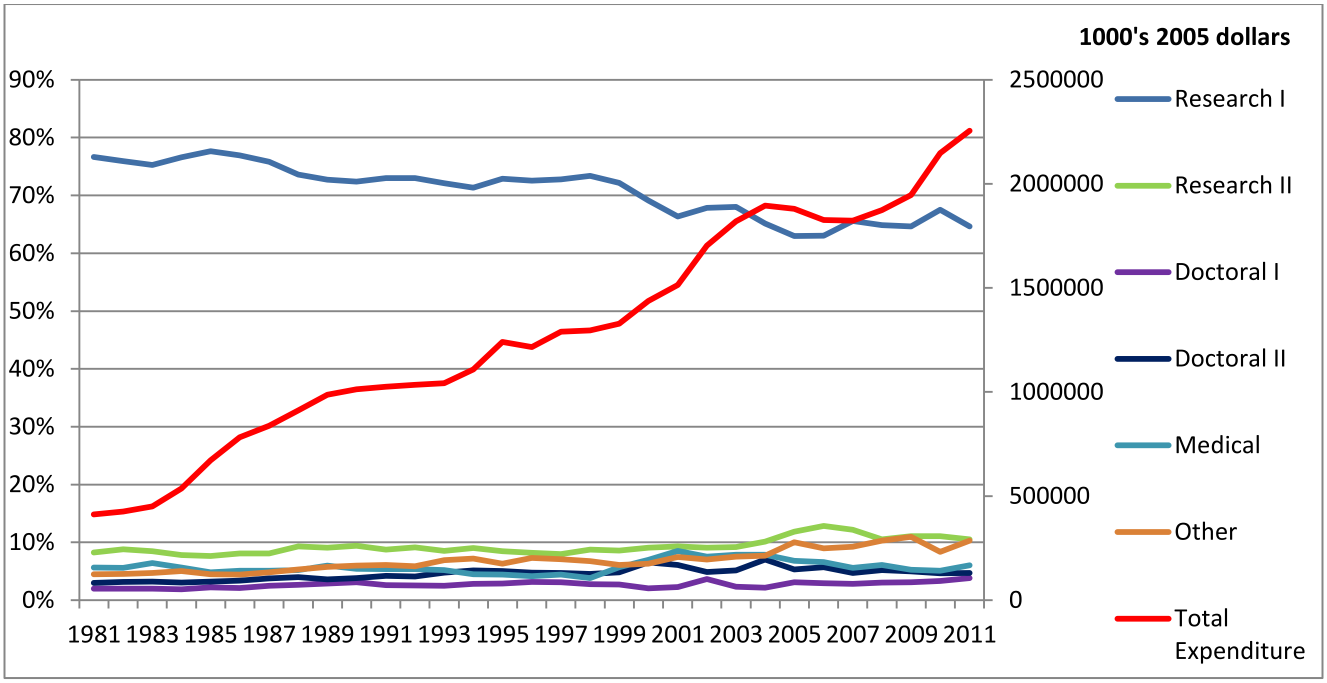


Source: (Stephan, 2012)

Appendix D: Equipment Expenditures

Figure D.1

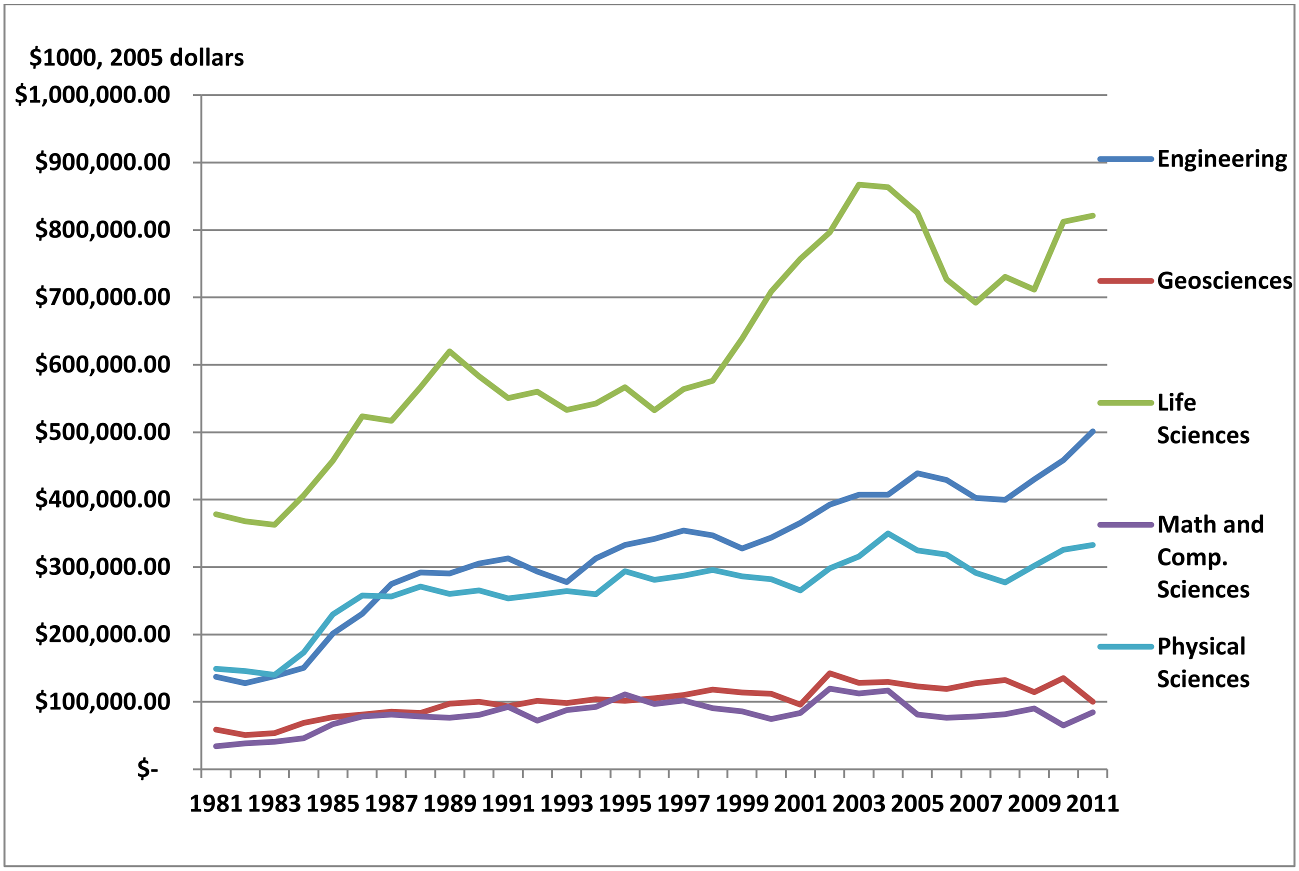
Equipment Expenditures for Research: Total and by Carnegie Classification, 1981-2011



Source: Equipment comes from NSF Higher Education Research and Development Survey; Webcaspar.

Figure D.2

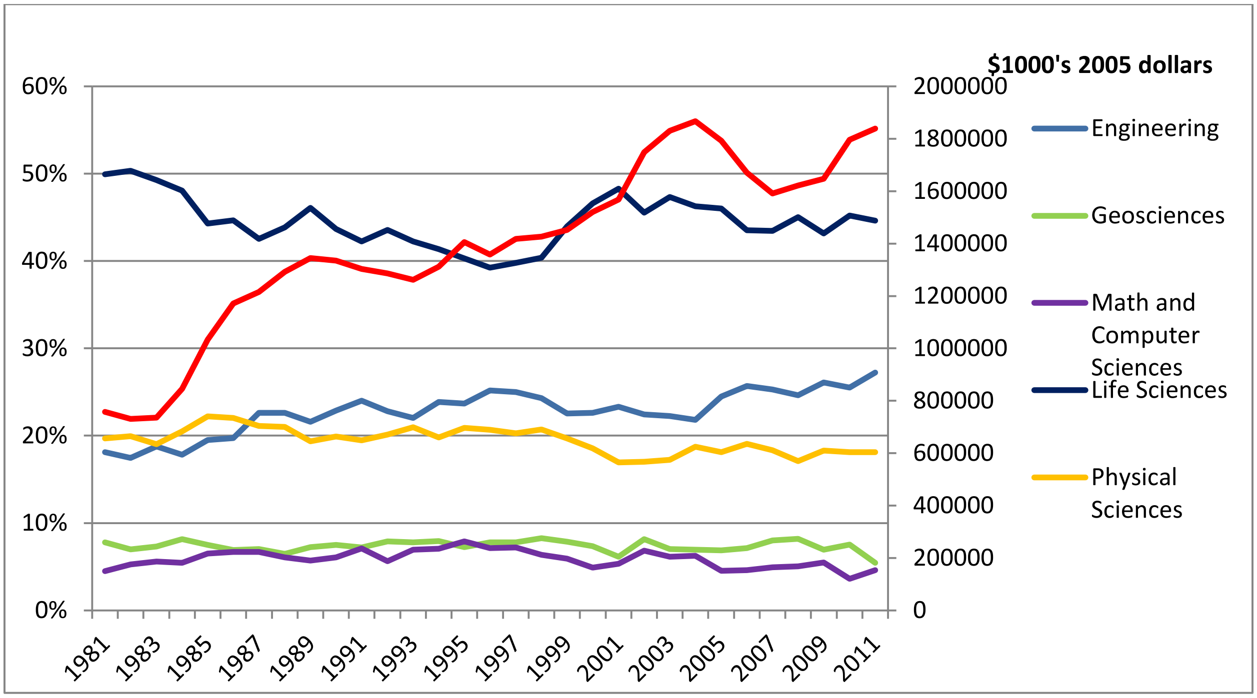
Real Equipment Expenditures by Field



Source: Equipment comes from NSF Higher Education Research and Development Survey; Webcaspar.

Figure D.3

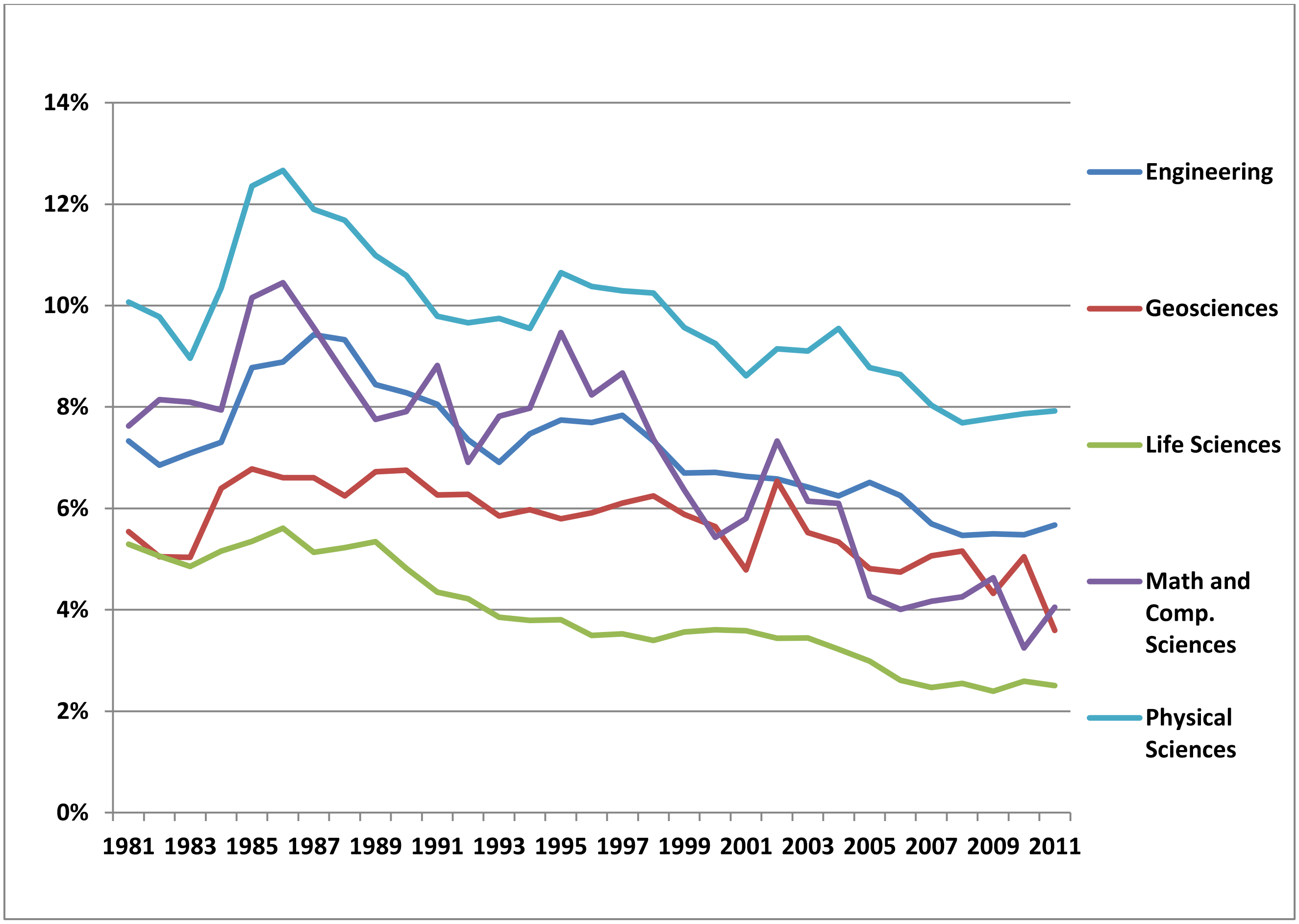
Share of Equipment Expenditures by Field and Total



Source: Equipment comes from NSF Higher Education Research and Development Survey; Webcaspar.

Figure D.4

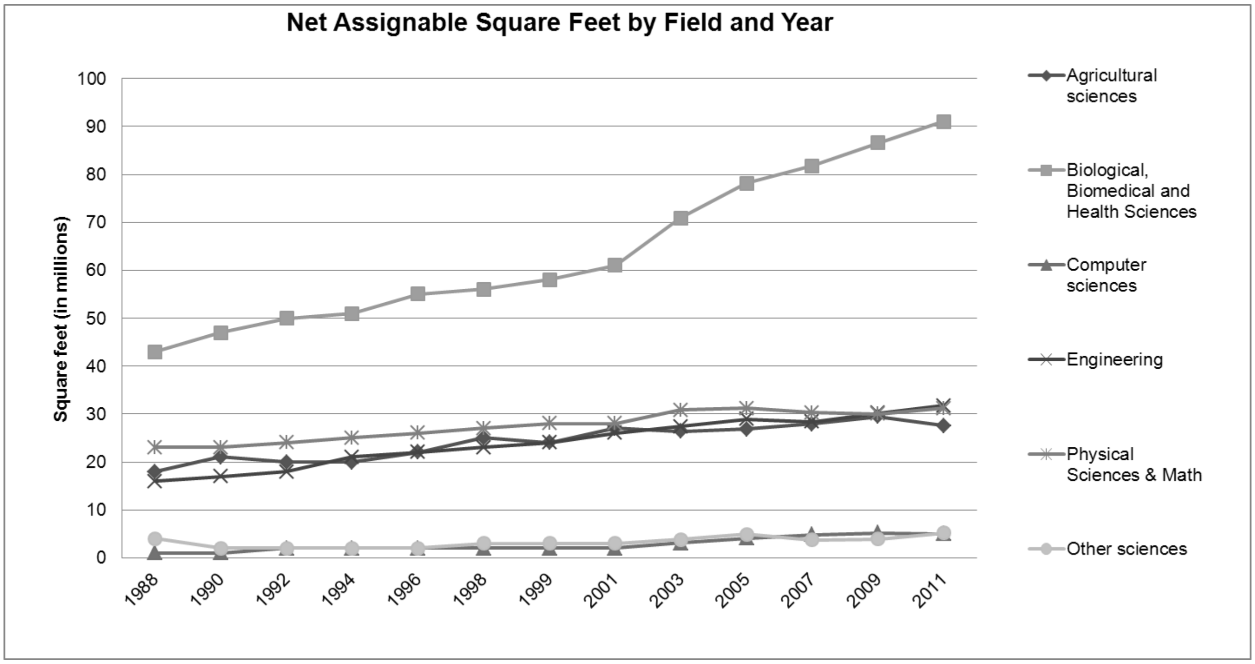
Percent of R&D Spent on Equipment by Field



Source: Equipment comes from NSF Higher Education Research and Development Survey; Webcaspar.

Appendix E: Space for Research

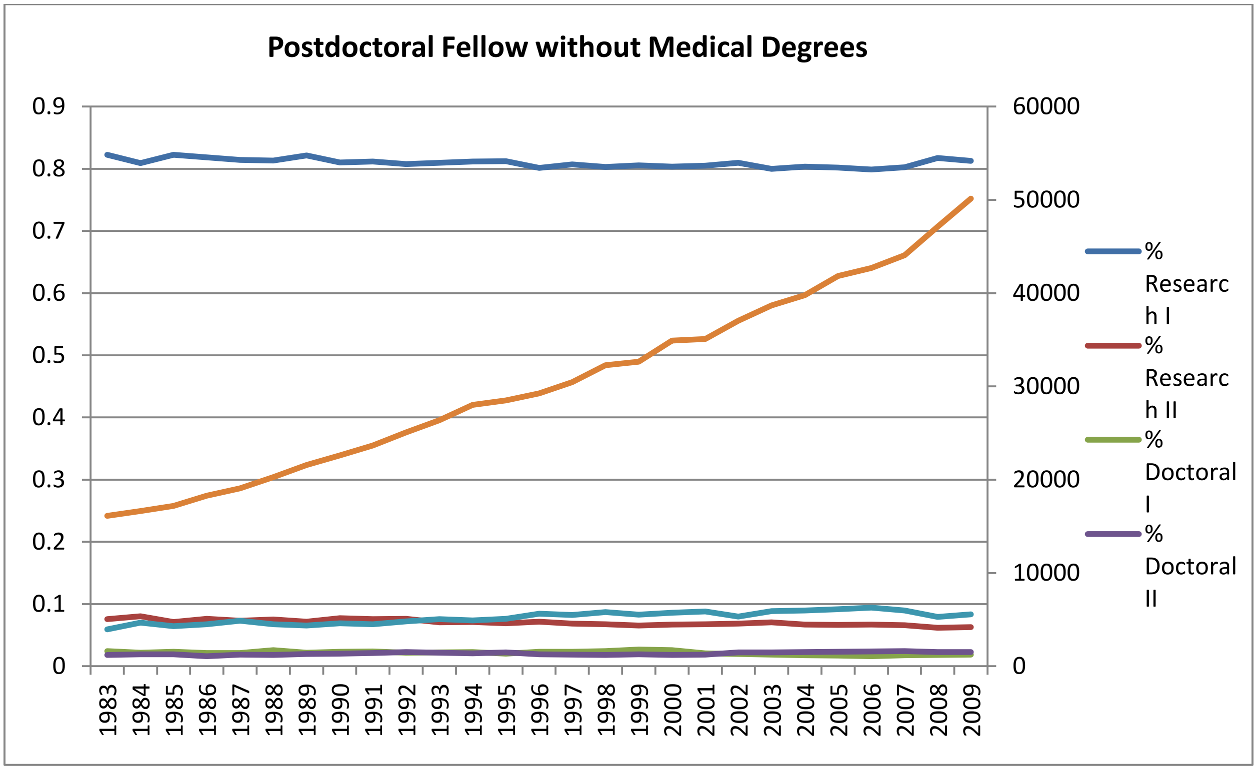
Figure E.1 Net Assignable Square Feed by Field and Year



National Science Foundation, Science and Engineering Research Facilities, 13-309, 2013

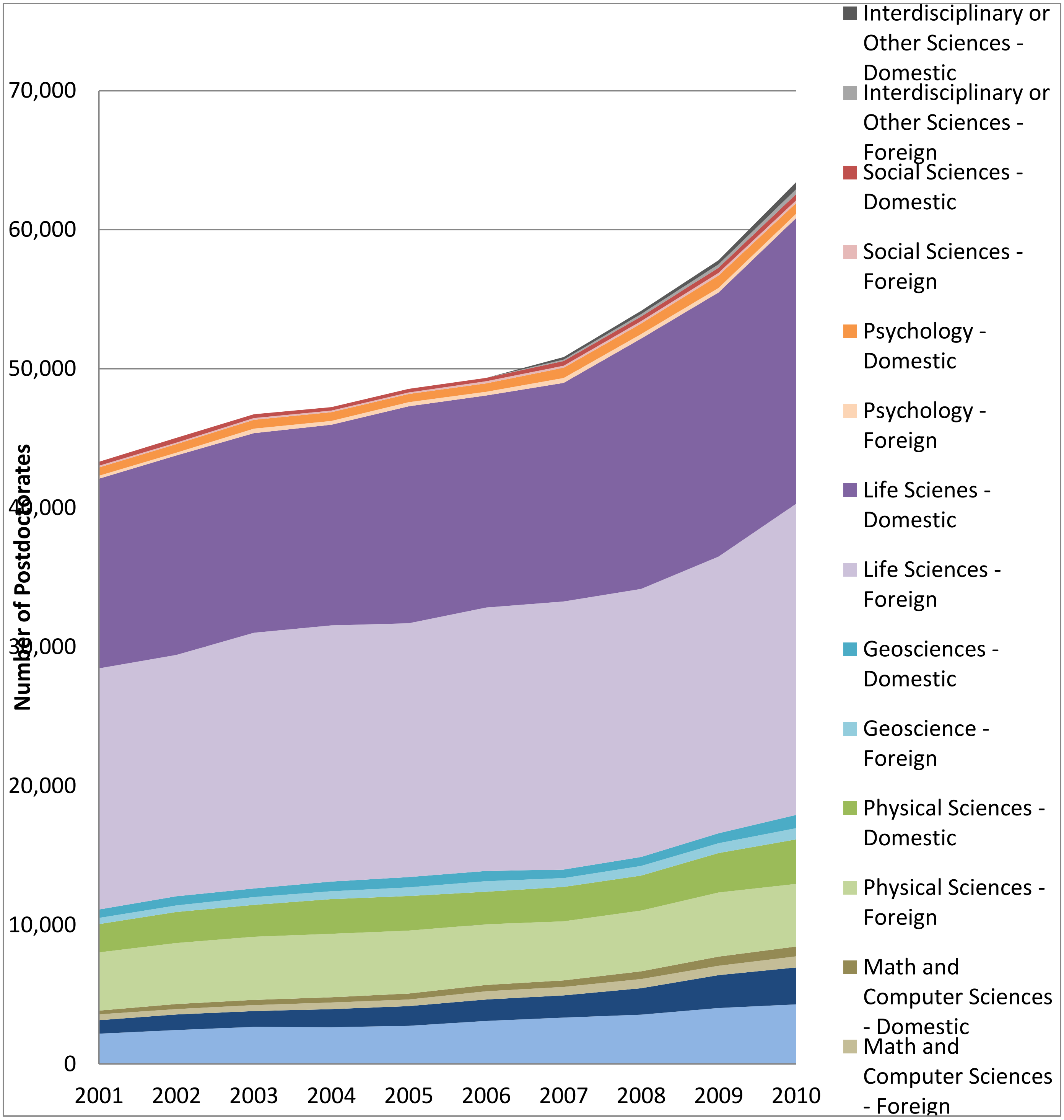
Appendix F: Postdoctoral Positions

Figure F.1 Postdoctoral Fellows without Medical Degrees by Carnegie Classification



Source: Webcaspar, GSS

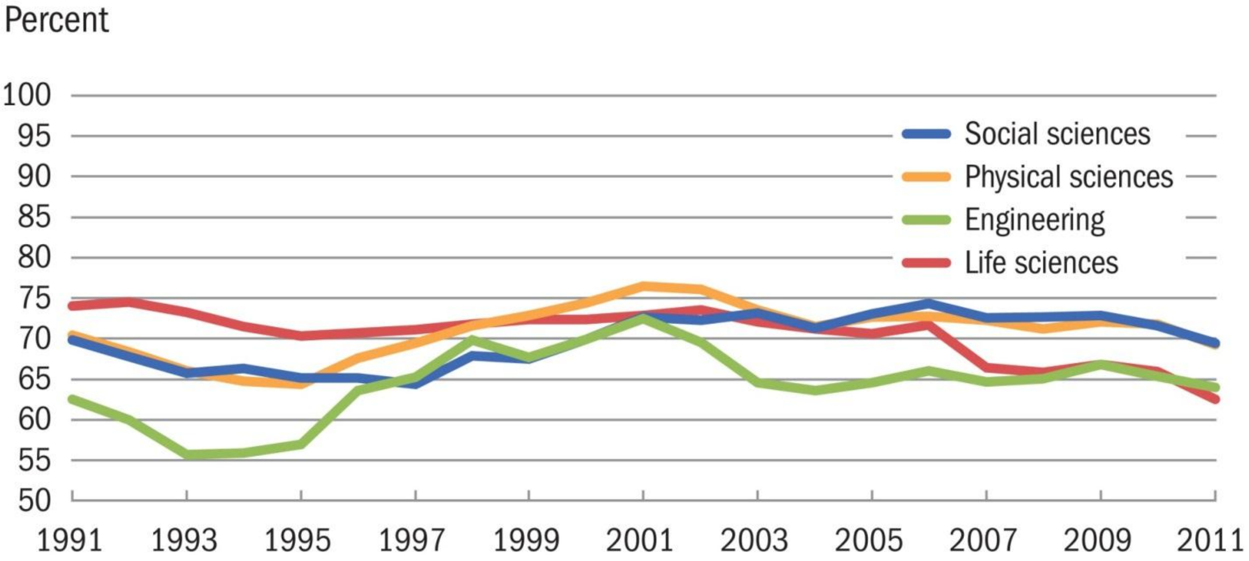
Figure F.2 Postdoctoral Positions by Field and by Citizenship status



Source: Webcaspar

Appendix G. Job Market Outcomes for New PhDs

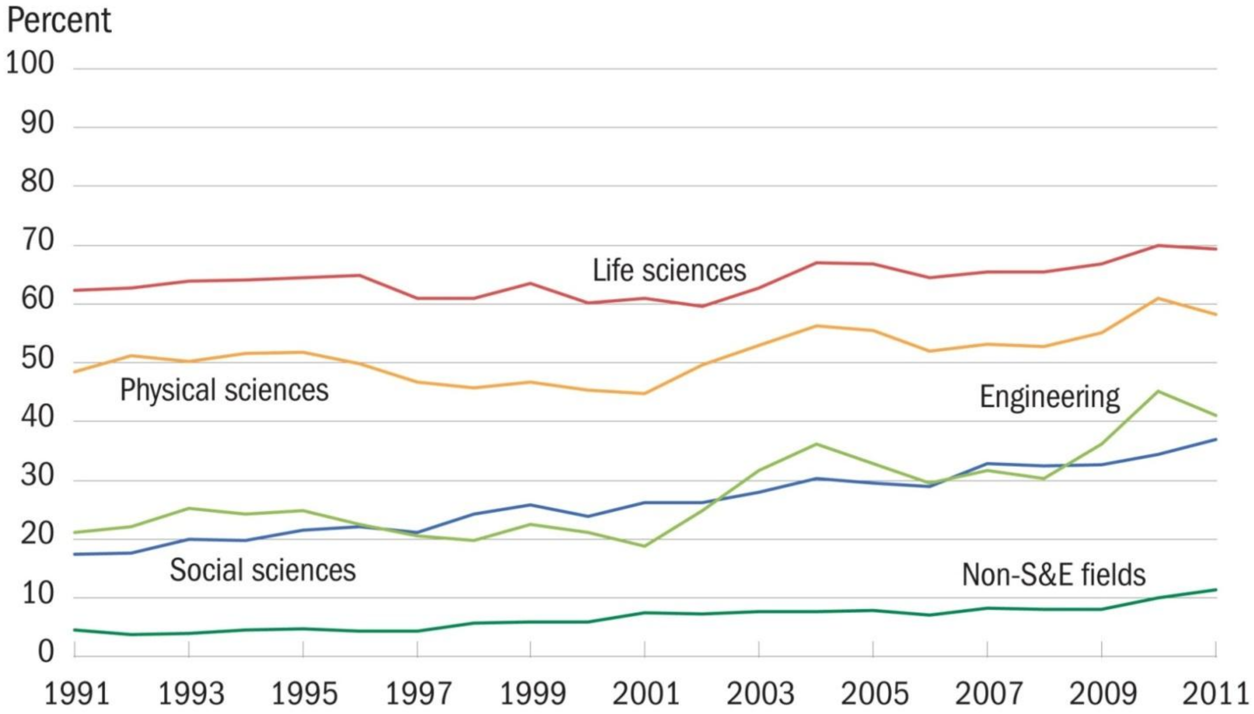
Figure G.1 Percent of Doctorates with Definite Commitments, 1991-2011



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.

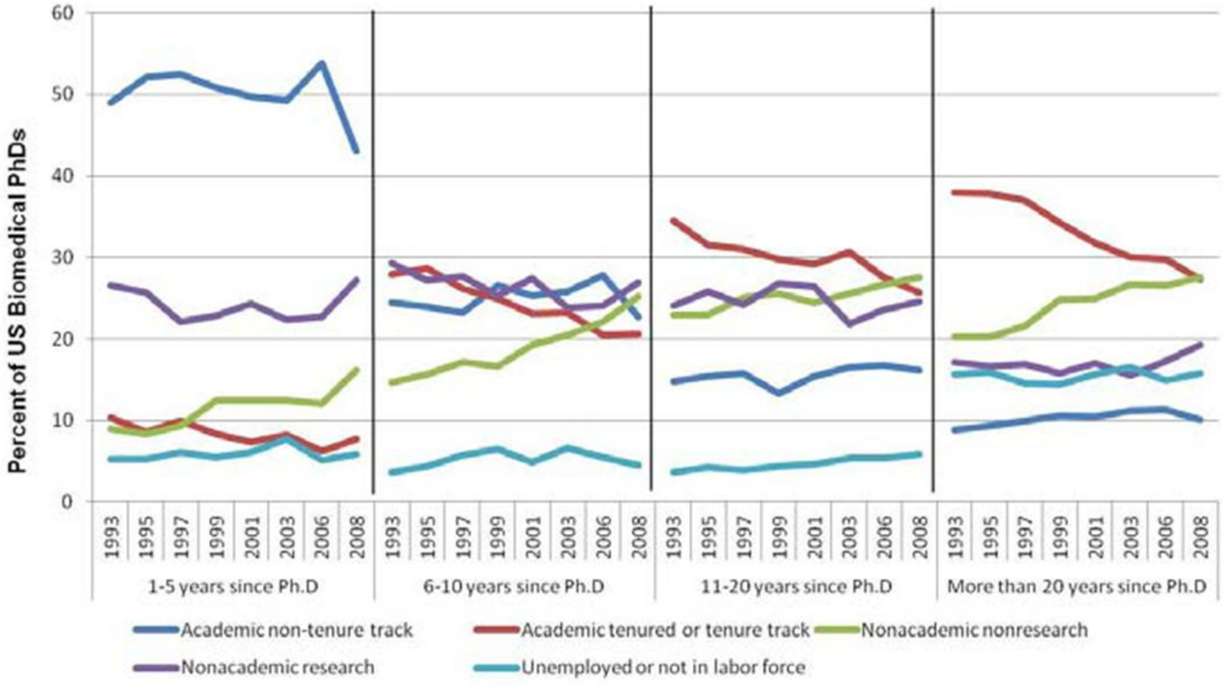
Doctorate Recipients from U.S. Universities 2011. Related detailed data: tables 42, 43.

Figure G.2 Percent of PhDs with Definite Commitments Taking Postdoctoral Position, 1991-2011



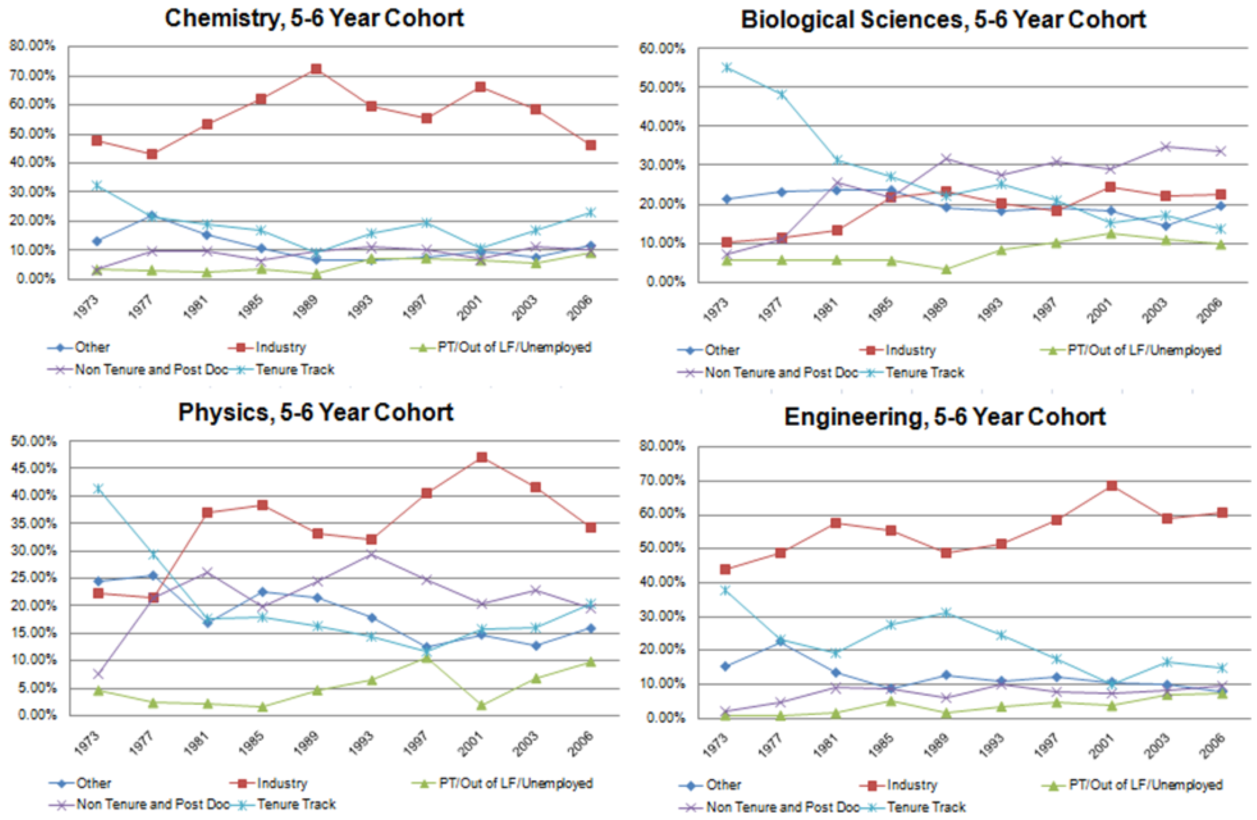
Doctorate Recipients from U.S. Universities 2011. Related detailed data: tables 44, 52.

Figure G.3 Employment Outcomes by Cohort, Biomedical Workforce



Source: Biomedical Workforce Report

Figure G.4 Job Position by Field, Five-and-Six-Year Cohort, 1973-2006



Chemistry, 5-6 Year Cohort

Biological Sciences, 5-6 Year Cohort

Physics, 5-6 Year Cohort

Engineering, 5-6 Year Cohort

Source: (Stephan, 2012).

Appendix H Institutional Expenditures for University Research

Figure H.1 Institutional Expenditures for R&D, Constant 2008 Dollars by Percent of Total Expenditures for University R&D

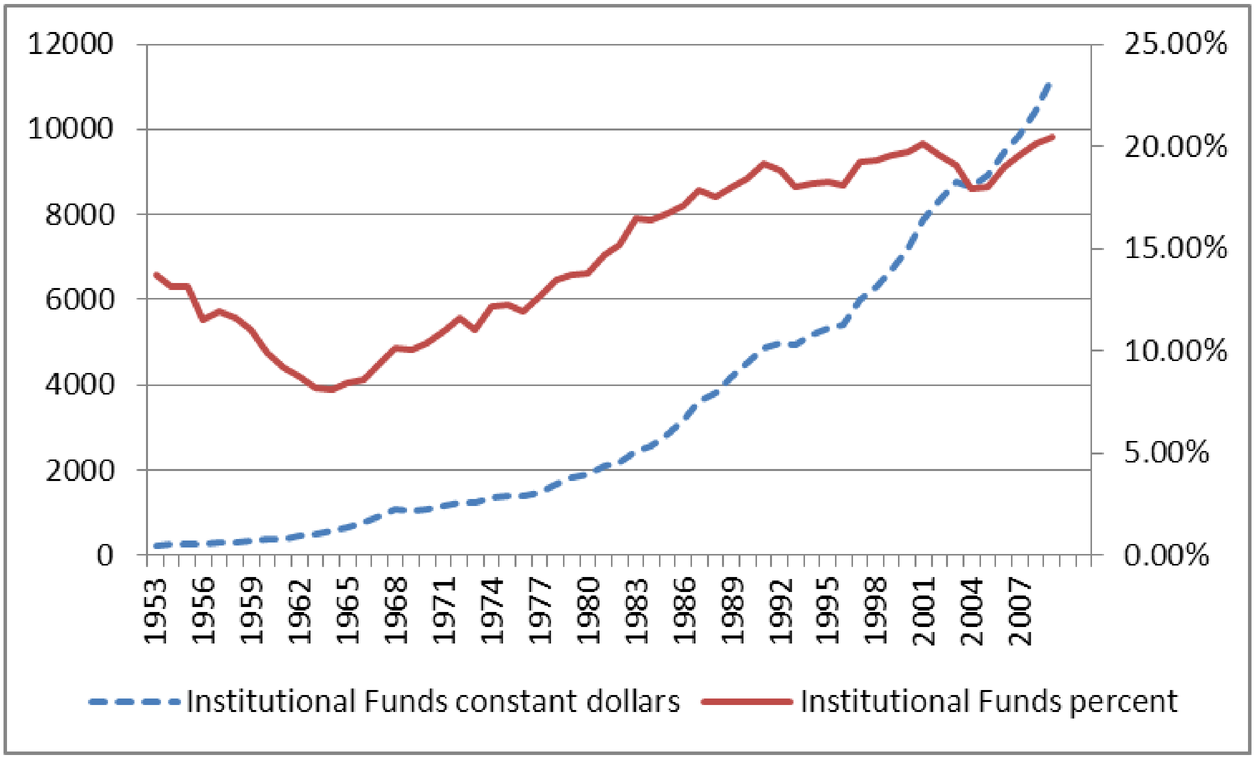


Figure H.2: Median Endowment Funds Constant 2011 Dollars, 1993-2011

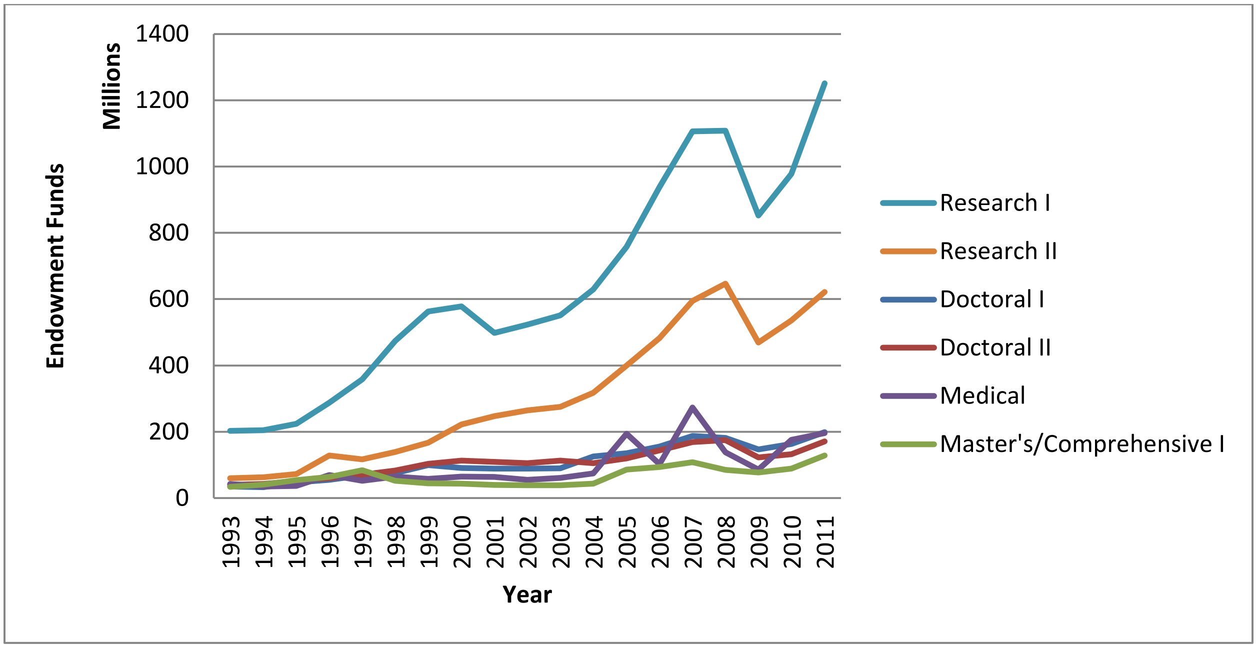
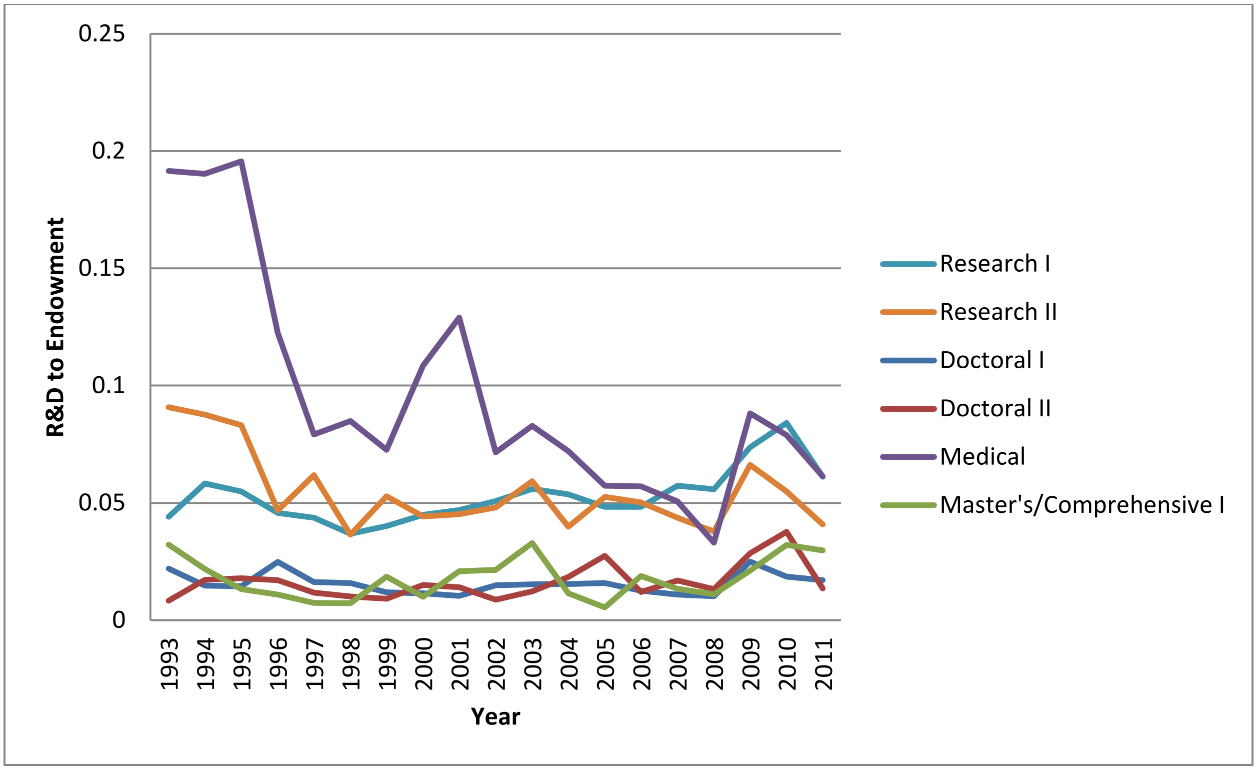
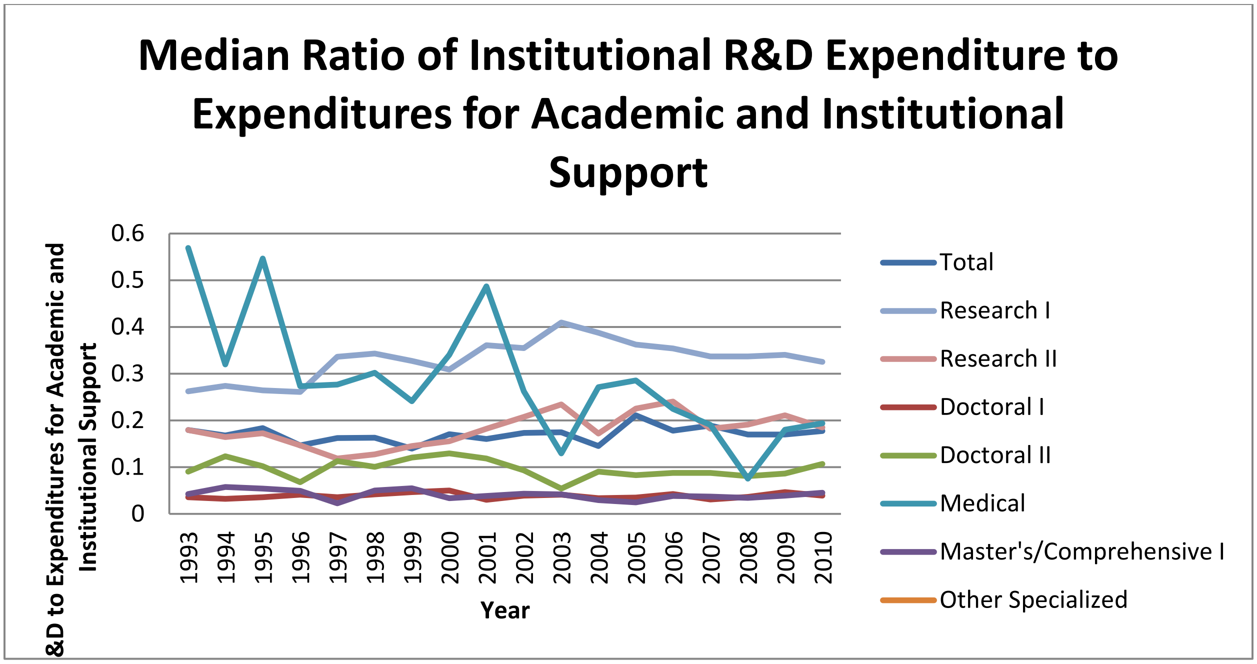


Figure H.3 Median Ratio of Institutional Expenditures for University Research and Development to Endowment Value, 1992-2011



Note: Ratio computed for institutions reporting in that year a positive R&D expenditure value; Source NACUBO and Webcaspar

Figure H.4 Median Ration of Institutional R&D Expenditures for University R&D to University Expenditures for Academic and Institutional Support, 1993-2011



Note: Ratio computed for institutions reporting in that year a positive R&D expenditure value; Source IPEDS, http://nces.ed.gov/ipeds/deltacostproject/ and Webcaspar.