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Research Universities: Core of the US science and technology system

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Abstract

Research universities are a recent innovation, having emerged in Prussia in the early 19th century, and in the United States only in the aftermath of the Civil War. By 1940, perhaps a dozen American universities could be regarded as first-class research institutions. However, they received virtually no financial support from the US government. The most far-reaching recommendation of Vannevar Bush's famous July 1945 report, *Science—the Endless Frontier*, was that it was in the nation's best interest for the federal government to fund university research. From 1950 through the mid-1970s, such federal support expanded rapidly, resulting in the flowering of the American academic research system, but was accompanied by a decline in industrial support. Beginning in the late 1970s, several federal agencies established largely successful programs to encourage university–industry research cooperation as a means of reestablishing links between universities and industry. Other countries have tried to replicate the success of US research universities, but with limited results. Yet despite the success of US universities, they face a number of significant challenges. The record of the past 60 years suggests that they can continue to remain at the forefront in the search for knowledge, but only if they, and the wider US public, understand and are prepared to deal with these challenges.

Keywords: US Research Universities; US science and technology system; Vannevar Bush; Universities in the middle ages and enlightenment; University research in Europe and Asia; University–industry cooperative research; Bayh-Dole Act

1. Introduction

Since the 1970s, research universities have been widely recognized as the core of this nation's science and technology system. Yet until World War II research universities were decidedly on the periphery of that system. Their ascendancy was in large measure due to the remarkable research contributions they made during the war that proved crucial to the war effort. Prior to the war, universities received virtually no federal funding for research, particularly basic research, and the concept of such funding was viewed as a radical idea. The report *Science—the Endless Frontier*, submitted by Vannevar Bush to President Harry Truman in July 1945, established both the legitimacy and the need for federal support of university research.

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Research universities are a relatively recent innovation. For most of their history, beginning in the 11th and 12th centuries, European universities were teaching institutions, which attracted students to lectures by eminent scholars. It was only in the 19th century that German universities began to require their faculties to engage in the production as well as the dissemination of knowledge. The German model began to be replicated in the United States (US) following the Civil War. By the turn of the century there were perhaps a dozen credible research universities in this country, a handful of them approaching world-class status.

US research universities are vital centers for the performance of research that advances knowledge in all science and engineering disciplines, contributing to the national economy as well as to local and regional economies. That the US university system today is undoubtedly the best in the world can be gauged by several indicators, including the number of Nobel Prizes awarded to faculty members, and the fact that US graduate schools are favored destinations for aspiring scientists and engineers from abroad. Several countries have tried to replicate the success of the US university system, but with limited results. One probable reason is that, unlike the circumstances in the United States, most foreign university systems are highly centralized and subject to control by a Ministry of Education.

Yet, US research universities face a number of problems and cannot afford to rest on their laurels or assume that the larger society appreciates the essential role they play in the nation's well-being. The quality of research and teaching provided by East Asian universities has been improving rapidly in recent years. As in other regions of the world, these universities (particularly in China) aspire to become competitive with universities in the United States, and may have considerable success in the future. However, the record for the past 60 years suggests that US universities can continue to compete successfully in the world market for knowledge. But they can do so only if they understand the challenges ahead and are prepared to respond to them.

2. Origins of universities in the middle ages and the enlightenment

The first European universities that emerged during the 11th to 13th centuries (starting with Bologna, Paris, and Oxford) were, almost exclusively, teaching institutions. Students were attracted to these centers of learning to hear lectures by prominent scholars who were at first largely clerics and later increasingly secular authorities [1]. The more eminent of these scholars sometimes published their lectures as well as results of their independent investigations and speculations. However, their income was derived primarily from teaching, although it could be supplemented by sales of books or by royal, noble, or clerical patronage. The eminence of a university's faculty was important in attracting good students. Since the leading European universities were acknowledged as centers of learning, they brought prestige to the cities and countries where they were located and were patronized for that reason. Nevertheless, they were devoted to the transmission rather than the production of knowledge.

Although universities became more formal organizations, and their curricula broadened as the centuries progressed, they remained primarily teaching institutions until the 19th century. Universities, however, were not the only centers of learning. The leading natural philosophers of the scientific revolution of the 16th and 17th centuries were supported in a variety of ways. Nicholas Copernicus spent most of his life as a canon in a remote Polish cathedral. Tycho Brahe was an independently wealth nobleman who was patronized by the King of Denmark and, later, by the Holy Roman Emperor. Johannes Kepler served as an assistant to Brahe and, after the latter's death, succeeded him as court astronomer to the Holy Roman Emperor [2]. (Among the duties of court astronomers at that time was to cast horoscopes.) Galileo Galilei published his first results in astronomy and mechanics while teaching at the University of Padua, then moved to Florence under the patronage of the Grand Duke of Tuscany. (In applying for the latter position, Galileo emphasized that he would have more time to pursue his research if not burdened with the need to take on students!) As Professor of Mathematics at Cambridge University, Isaac Newton conducted most of his research in astronomy, mechanics, optics, and alchemy [3]. However, he conducted this research as an "amateur" since he was paid to teach.

The first academies of science (although not necessarily designated as such) were established in the 17th century in recognition of the rising importance of natural philosophy and other scholarly pursuits, most notably the Académie Française in 1635 and the Royal Society of London in 1660 [4], although (particularly in the first example) their members included eminent scholars in areas other than natural philosophy. Indeed, one of the charges of the Académie Française was (and remains) to preserve the purity of the French language. These learned bodies, which were granted royal charters in recognition of the importance of their cultural contributions, were established to facilitate scholarly communication. They complemented rather than superseded the universities in their respective countries. Members of the Royal Society, such as Isaac Newton, were sometimes university professors. More often, they were either independently wealthy ‘‘amateur’’ scientists or individuals in various professions. An example in the latter category was William Gilbert, a physician who carried out the first systematic experiments in magnetism during the 17th century. Isaac Newton's *Principia* was published in 1689 by the Royal Society when he himself was its president. At about the same time, Newton resigned his professorship at Cambridge to become Master of the Mint.

The pattern of colleges as teaching institutions complemented by learned societies was imported into North America by British settlers during the colonial era, beginning with the foundation of Harvard College in 1636, Benjamin Franklin, who was the most eminent scientist in the pre-revolutionary period, derived his income from his printing business. In 1743, he took the lead in establishing the American Philosophical Society in Philadelphia, modeled after the Royal Society of London [5]. While today Franklin is often thought of as a statesman who dabbled in research earlier in his life, his contemporaries more properly regarded him primarily as a scientist who later became a statesman [6]. During the summer of 1776, Franklin was designated as Minister to France by the Continental Congress; his fame as a scientist provided him with immediate entry to scientific circles in Paris and, through them, to political circles.

As the United States expanded westward during the last decade of the 18th century and early decades of the 19th centuries, colleges were created in the newly settled territories, mainly to teach practical knowledge to young people in the frontier regions. Also established were state and regional academies of science, modeled after Franklin's Philosophical Society and John Adams' American Academy of Arts and Sciences, founded in Boston in 1790. Until the Civil War, scientific research—mainly applied—was conducted as a profession exclusively in US government organizations: first in military bureaus such as the Coast and Geodesic Survey, later in civilian bureaus such as the US Geological Survey which were spun off from the military [7]. Professors in American colleges sometimes served as paid consultants to these government organizations, but purely in their individual capacities. The universities themselves did not receive financial support for research from the government. However, some professors conducted basic research. The most famous of these was Joseph Henry, Professor of Physics at Princeton, who made fundamental contributions to electromagnetism and later became the first Secretary of the Smithsonian Institution ([7], p. 66–90) and one of the prime movers in the founding of the US National Academy of Sciences (NAS) in 1863 ([7], p. 135–41).

3. Research universities in the 19th and early 20th centuries

Germany, more particularly Prussia, was the site of the somewhat radical transformation of universities as teaching institutions devoted to the transmission of knowledge to places for research as well—that is, institutions dedicated to both the production and transmission of knowledge. This transition first occurred early in the 19th century in the humanities and, more particularly, the classical languages. Prior to that time, the scholarship of professors of the classics at universities throughout Europe typically consisted of new translations of Greek and Latin texts, commentaries on the continuing relevance of those texts, and occasional original poems and essays in those languages. According to German idealist philosophers, a balanced development of state and society was only feasible with educated citizens trained as students in a neutral atmosphere of truth-seeking. Alexander von Humboldt incorporated these ideals into plans for a new university, the University of Berlin, founded in 1809 [8].

By 1820, classical language faculties at Berlin and a few other German universities had turned their attention to scholarly research in areas such as philology and linguistics which required access to original texts. Given this new emphasis, faculty with access to great libraries and museums, such as Humboldt University, enjoyed a decided advantage over those at universities in smaller cities such as Wittenberg.[1]

[1]This transition in the classics was emphasized by the rise and eventual dominance of Sanskrit studies in Germany. Sanskrit studies had first been established at Oxford and Cambridge during the final years of the 18th century by former employees of the British East India Company who had learned the language while posted in India. The Sanskrit scholarship of the faculties at Oxford and Cambridge

The first scientific laboratory devoted to both teaching and research was established by the German chemist Justus Liebig at Giessen in 1826. With the rise of technology-based industry in the German states during the 1860s, which accelerated after German unification in 1870, the scientific research faculties at these universities became an asset to the country's industrial concerns.

The first quasi-research universities in the United States were the land grant colleges created by the Morrill Act of 1862, whereby lands belonging to the US government were transferred to the states on condition that proceeds from their sale of land was to be used to establish colleges (and later universities) to teach practical science, primarily in agriculture and the mechanical sciences ([7], p. 263) Faculty members at these institutions were also expected to conduct research in their areas of specialty (primarily in agriculture) and to create outreach programs to disseminate the results of their investigations to farmers in their respective states.

The growing importance of science to the United States was given official recognition in 1863 when the US Congress created the NAS, a self perpetuating organization of leading US scientists chartered to provide advice, when so requested by the US government ([7], p. 263). The government rarely called upon NAS for advice until 1916 when a new research arm, the National Research Council (NRC), was created a year prior to US entry into World War I. Since the 1950s, NAS and its sister organizations, the National Academy of Engineering and the Institute of Medicine, have issued numerous authoritative reports through NRC on a wide range of science and technology issues at the request of one or more executive branch agencies or the US Congress.

Despite the precedent established by the Morrill Act, the first US universities whose faculties were expected to engage in research as well as teaching were created only in the aftermath of the Civil War. These universities were established on the German model. This expanded role of US colleges initially occurred when those institutions, established during the colonial period, began to transform themselves into research universities. For example, in the early 1870s Harvard created the Jefferson Physical Laboratory, the first American university facility devoted exclusively to research and teaching in a scientific discipline. However, newer universities founded after the Civil War soon took over the lead from the old line Eastern seaboard institutions in initiating the tradition of research universities in the United States. Johns Hopkins University, founded in 1876, was the first American university to be established from the outset as a research university; during its first two decades, it produced more graduates with PhD degrees than Harvard and Yale combined [9]. Johns Hopkins was followed by Clark University (1889), Stanford University (1891), and the University of Chicago (1892). By the turn of the century, several state universities had established their credentials as leading research institutions, including the universities of California, Michigan, Wisconsin, Minnesota, and Illinois.[2]

Thus, by World War I research universities had joined federal government laboratories as sites where organized, "professionalized" scientific research was conducted in the United States. Industrial research laboratories began to be established almost immediately after the war and by the 1930s the industrial sector had come to dominate research in the country, although as with the government sector, the bulk of its research was applied. In contrast, universities and a few private, non-profit institutions such as the Carnegie Institution and the Battelle Foundation accounted for virtually all of the country's basic research. Universities too conducted considerable applied research, often under contracts from industrial concerns or federal organizations.[3] As a result of the Great Depression research in all three sectors declined during the 1930s. By 1940, however, their financial situation had improved significantly ([7], p. 326–67).

(*footnote continued*)
followed the lead of earlier classical scholarship: that is, it consisted of translations of well known texts, essays on the continuing relevance of Sanskrit writings, and occasional original poems in the language. When German scholars discovered Sanskrit around 1820, their research focused more on Sanskrit linguistics, which required more textual references. Although German Sanskrit scholarship often exhibited little interest in the substance of the texts being studied, by mid-century German Sanskrit scholarship had become widely (if grudgingly) accepted as the best in Europe. (*NB: This story was related to one of us—WAB—in 1972 by the then Professor of Sanskrit at Harvard.*)

[2]In 1906, James Cattell counted the top 1000 scientists in the nation. Based on the number of scientists in this group, the 15 leading American research universities were (in descending order): Harvard, Columbia, Chicago, Cornell, Johns Hopkins, California, Yale, Michigan, MIT, Wisconsin, Pennsylvania, Stanford, Princeton, Minnesota, and Illinois [10].

[3]The most prominent federal agency supporting university research during this period was the National Advisory Committee for Aeronautics (NACA) established in 1915, which was the predecessor of NASA.

4. Research universities in the 1940s

In 1940, total US expenditures for research and development (R&D) were estimated to have been approximately $345 million (or $3.75 billion in constant, inflation-adjusted 2000 dollars). Private industry accounted for $234 million, or 67.8% of these expenditures. The federal government was a distant second, accounting for $67 million, or 19.4%, universities and colleges accounted for $31 million, or 9.0%, with the remaining $13 million accounted for by other sources, including state governments and non-profit institutions. By comparison, total national expenditures in 2004, measured in constant, inflation-adjusted 2000 dollars were $288.4 billion, with industry accounting for $183.9 billion or 63.8%, the federal government accounting for $86.3 billion, or 30.0%, and universities and colleges accounting for $10.3 billion, or 3.6%, out of their own funds [11,12].

Until World War II, private universities obtained their research support from their endowments and from non-profit foundations, and state universities from state governments [13]. During the academic year 1939/40, 10 of the estimated 150 research universities in the United States performed $9.3 million or 35% of the total of $26.2 million in research performed in the natural sciences and engineering by the academic sector, while 35 of these 150 institutions performed $16.6 million or 63% of the academic total [14].

World War II significantly altered the US science and technology enterprise including, most prominently, its academic research sector. On June 12, 1940, President Franklin D. Roosevelt issued an executive order to create the National Defense Research Council (NDRC). The NDRC was chaired by Vannevar Bush, formerly Dean of Engineering at the Massachusetts Institute of Technology (MIT) and then President of the Carnegie Institution of Washington. Its other members were James B. Conant, President of Harvard, Karl Compton, President of MIT, and Frank Jewett, President of the Bell Laboratories and of the NAS. The council was charged with exploring the problem of organizing the nation's scientific resources in preparation for what Roosevelt and its members regarded as the inevitable US entry into what was still a purely European war. On June 28, 1941, the president created the Office of Scientific Research and Development (OSRD) within the Executive Office of the President. OSRD, also chaired by Bush, was given considerably more authority than the NDRC, in particular, the authority to contract for R&D for military purposes. NDRC, now chaired by Conant, became one of two units within OSRD, the other one devoted to relevant medical research ([13], p. 1–8).

One key to the success of the OSRD as implemented by Bush and his senior associates was to allow scientists and engineers to conduct their wartime activities in settings as close as possible to their accustomed venues—that is, in university and industrial research laboratories. The most costly and famous of the wartime R&D projects was the Manhattan Project (to develop the first nuclear weapons) which OSRD oversaw but did not manage. R&D at the Los Alamos Laboratory in New Mexico was managed by the University of California under a government contract, while the US Army Corps of Engineers managed its associated facilities. The Manhattan Project, however, was an exception to Bush's system, since he and his senior associates recognized that totally new laboratories would be required for such a massive project. Thus, for example, they created several entirely new facilities such as the Oak Ridge National Laboratory, the Savannah River site, and the Hanford, WA, facility, all of them managed by industrial concerns rather than universities. A better example of how the OSRD system worked was the Radiation Laboratory (or Rad Lab) at MIT where successively superior radar systems were developed and tested. Prominent scientists were recruited to the highly secret Rad Lab to work on these systems beginning soon after the creation of OSRD ([13], p. 1–10).

As the war drew to a close, key figures including Roosevelt, Bush and his associates, and scientists conducting research at wartime laboratories, began to think seriously about the character of the US research system in the post-war era. On November 17, 1944, the president wrote a letter to Bush asking him to answer four questions, all of them related to how the lessons derived from the experiences of the war could be used to shape the post-war research system in the United States. In response, Bush convened four committees of scientist and engineers, each charged with answering one of Roosevelt's four questions in detail. Bush himself provided an overview and summary of the four committee reports, to which he added his own commentary and recommendations. This report, entitled *Science—the Endless Frontier* (*SEF* or the Bush report), was transmitted to President Harry S. Truman on July 5, 1945. The report proper consisted of Bush's overview and summary, with the reports of the four committees appearing as appendices [14].

Prior to World War II, as previously noted, the US government provided virtually no support for research in universities, the exceptions being occasional contracts from federal agencies. Thus, *SEF*s most original and far-reaching proposition was that the government had not only the authority but, indeed, the obligation to support research, particularly basic research, in universities. In the pre-war era, US industry had relied heavily on basic research conducted in Europe as a basis for its applied research and development. But since the European research system had been devastated during the war, Bush and his associates recognized that henceforth the United States would have to rely on its own resources to perform the basic research required by industry. According to a metaphor favored by Bush, university basic research results should maintain and replenish the pool of knowledge on which industry could draw. The Bush report went on to argue that US industry lacked the economic incentive either to perform or support the bulk of the basic research it would require in the post-war era. The results of basic research are widely disseminated by means of scientific publications and presentations at professional society meetings. Thus, they are non-proprietary in character; following Bush's metaphor, anyone can drink from the pool of knowledge. Thus, with some exceptions, any industrial firm which devoted significant resources to the conduct of basic research would be unlikely to recoup its investment. In contrast, the federal government had an incentive to support basic research as a public good.

The Bush report made four enduring contributions to the conceptualization of science policy in the United States ([13], p. 1–10, 12).

First, *SEF* advanced the position that the proper concern of US science policy ought to be the support, as opposed to the utilization, of science, except to fulfill its own Constitutional responsibilities such as, most obviously, national defense.

Second, it advanced the proposition that basic research ought to be the principal focus of federal support for science, again with the exception of national defense.

Third, it argued that mechanisms for the support of research must be consistent with the norms of the practitioners of that research who would, of course, be its direct beneficiaries.

The *fourth* proposition, although not articulated explicitly, followed as a logical consequence of these three and has had the most enduring effect on the evolution of science policy in the United States. By arguing for the primacy of basic research, *SEF* suggested that universities, as the principal sites for the conduct of basic research and the exclusive sites for graduate and post-graduate education, literally defined whatever national research system could be said to exist in the United States. Prior to World War II, the nation's research universities were usually thought of as being on the periphery of the US scientific enterprise. The Bush report argued, by implication, that they should constitute its core.

Although the Bush report included several recommendations for upgrading the research capabilities of existing federal agencies, it argued that all government support for basic research ought to be channeled through a new agency. The report referred to this new agency as the National Research Foundation. During the course of congressional hearings in the fall of 1945, the name of this proposed agency became the National Science Foundation (NSF).

On July 5, 1945, in a letter transmitting his report to President Truman, Bush noted that, "It is clear from President Roosevelt's letter [of November 17, 1944, asking four questions which resulted in *SEF*] that in speaking of science he had in mind the natural sciences, including biology, and I have so interpreted these questions. Progress in other fields, such as the social sciences and the humanities, is likewise important; but the program for science presented in my report warrants immediate attention." ([14], p. 1). In fact Bush, who was politically conservative, seems to have had a visceral distrust of the social sciences, perhaps because of his recollections of the 1930s when several leading, left-wing practitioners of those disciplines had promoted them as a means for social engineering. In any event, the May 1950 legislation which created the NSF did not list the social sciences explicitly as one of the areas in which NSF was authorized to provide research support. Instead, it combined them into an "other sciences" category at the end of the following list: mathematical, physical, biological, engineering, and other sciences. Research in the social sciences was explicitly listed as being eligible for research support in a 1960 congressional amendment to the National Science Foundation Act of 1950.

In 1947, the Republican-controlled 80th Congress passed a bill to create a NSF. According to this bill a 24-member National Science Board, consisting of distinguished individuals appointed by the president for 6-year terms, was given authority to hire and, by implication, fire the NSF director. President Truman vetoed this bill on the grounds that no group of private citizens—namely, the National Science Board—should have ultimate authority over the disbursement of appropriated funds ([15], p. 34–40). Compromise legislation to create the proposed NSF was finally reached and the enabling legislation signed into law on May 10, 1950 [16]. But in the interim, several federal agencies heeded the Bush report's call to support research, particularly basic research, in universities. The Office of Naval Research (ONR) and the Atomic Energy Commission (AEC), both created in 1946, took the lead in doing so. Starting with ONR, several organizations within the Department of Defense began to support university research related broadly to their basic missions. The laser and advances in computer science were outgrowths of this research. During the early 1980s, the Defense Advanced Research Projects Agency (DARPA) supported university research leading to the development of the Internet.

When OSRD was abolished at the end of 1947, its active contracts for medical research were assumed by the National Institutes of Health (NIH). The agency built upon this foundation to develop an extensive program of research grants to US medical schools. For several years after its creation in 1950, NSF remained a bit player among federal organizations that supported basic research in universities. However, within 2 years of the launching of Sputnik I by the Soviet Union in October 1957, NSFs research budget increased by approximately 250%. Thenceforth, its role in the support of university basic research was assured [15].

From the outset, peer review became a central feature of the NSFs procedures, as it became in NIH, the AEC (and in the Department of Energy which absorbed the AEC in 1974), and other agencies including NASA which also supports university research. That is, proposals submitted by university faculty through their university grants offices are evaluated for their scientific merit by scientific experts—or peers—of the proponents, and agency decisions on funding made on the basis of these evaluations.[4]

The legislation creating NSF also charged the agency with the support of education in mathematics, science, and engineering. It initiated such support in the spring of 1952 with its first awards of pre- and post-doctoral fellowships. Subsequently, NSF expanded the scope of its education activities. Concern was widespread following the launching of Sputnik that the United States was falling behind in its preparation of future scientists and engineers. Accordingly, in 1958 Congress passed the National Defense Education Act (NDEA) which, among other things, expanded the role of NSF in science education and related educational research. The following year, NSF began to fund disciplinary committees of university faculty to work with teachers to update and improve high school text books in their respective fields, as well as summer institutes to train teachers in the use of these materials. In 1968, Congress amended the National Science Act of 1950 to authorize the foundation "… to initiate and support … science education programs at all levels."[17]. As Title I of the Education for Economic Security Act of 1984, NSF was given the authority to award grants with the objective of improving education in mathematics and science "… to schools, local education agencies, museums, libraries and public broadcasting entities."[18].

5. Research universities: 1950–1975

The changing roles of research universities in the US science and technology system and in their relations with the other sectors of American society from 1950 to the present can be roughly divided into two periods: 1950–1975 and 1975 to the present.

During approximately the first two decades of the first of these periods, federal expenditures for R&D grew rapidly not only in absolute terms but as a percentage of total national R&D expenditures. In 1963, the federal government was accounting for approximately 68% of national R&D expenditures and industry approximately 30%, with other sources making up the approximately 2% balance. Thereafter, federal R&D as a percent of total national R&D expenditures declined. In 1979, the federal government and industry each accounted for approximately 48% of total R&D expenditures. Thereafter, the government's R&D expenditures as a percent of the total continued to decline, while industry's continued to increase ([11], p. 4–12).

The amount of research performed in US universities has continued to grow since the early 1950s, both in absolute dollars and as a percentage of total national R&D. In 1953, universities accounted for $273 million,

[4] ONR and DARPA do not use a formal peer review process, but instead consult widely with scientists before initiating new projects. These agencies believe that a structured peer review process can place constraints on the type of high-risk projects they want to pursue.

or 5.3%, of total national R&D expenditures of $5.18 billion.[5] The university share of total national R&D remained at slightly more than 5% until 1960, but by 1965 had risen to 7.9%, and by 1975 to 10.0%. In 2004, the last year for which data are available, universities performed $42.4 billion, or 13.6% of total national R&D expenditures of $312.1 billion (or $288.4 billion in constant, inflation-adjusted 2000 dollars). In fact, the university research sector has experienced greater growth since 1975 than either the industrial or federal research sectors.

The two decades from 1950 to 1970 witnessed the flowering of the American research university system as it came to be acknowledged as the core of the country's science and technology system. The social science and humanities faculties of research universities also saw their prestige increase as American universities competed to attract the best scholars in all academic disciplines, not just science and engineering. Since 1960, the research of university faculty in the social and behavioral sciences (particularly their more quantitatively oriented disciplines) have been supported by the NSF and several other federal agencies, although not nearly to the extent of the ''hard'' sciences.[6] The National Endowment for the Humanities awards research grants to scholars in the humanities.[7] However, humanities faculty members continue to rely heavily on private foundations for much of their research support. As a result of their relative paucity of support, some regard the humanities faculties as being in crisis and having become poor cousins to the science faculty [21].

The federal government's support for scientific research in universities underlay the flowering of the system. In 1953, the federal government accounted for 54.6% of the research performed in US colleges and universities, with industry accounting for 7.7%, the remainder being accounted for by the universities' own funds, by state and local governments, and by grants from private non-profit foundations. By 1970, the federal share had risen to 69.7%, while the industrial share had declined to 2.7%; comparable figures for 1975 were 67.2% and 3.3%. For reasons discussed presently, industrial contributions to university research began to rise after 1975, reaching an approximately 7% steady-state level by 1990. By that time, the federal share of university research support had declined to about 60% [21].

During the approximately 5 years from the end of World War II until the creation of the NSF in May 1950, the US government accepted a central argument of *SEF* that federal support for university research should be regarded as a public good, an investment that would yield tangible returns. During the quarter century following the war, American industry and the American economy as a whole expanded at an unprecedented rate. Economic analyses have identified investments in research as a significant factor in US economic growth.[8] Although quantitative, causal connections are difficult to make, by 1970 there was widespread agreement that the central proposition of *SEF* had been decisively demonstrated: research universities were a primary contributor to industrial and economic growth. Between 1945 and 1970, US presidents from both political parties subscribed to the proposition that the US government should fund research in US universities, and by 1970 there was a broad, bipartisan consensus in both houses of Congress that such support should indeed be provided.

The flowering of the US research universities during the quarter century following World War II also can be gauged in terms of intangible factors. For example, between 1950 and 1975, the 26 Nobel Prizes awarded in physics were either won outright or shared by Americans; the comparable figures for Nobel Prizes in chemistry

[5]Year 1953 was the first year in which consistent definitions of R&D expenditures in the industrial, government and academic research sectors were agreed upon. These definitions continue to be employed in collecting and reporting these data.

[6]For example, the fiscal year budget request for NSFs Directorate for Social, Economic and Behavioral Sciences is $214 million, compared with $1.15 billion for its Directorate for Mathematical and Physical Sciences, and a total budget request of approximately $6.02 billion [19].

[7]The National Endowment for the Humanities total budget request for fiscal year 2007 is approximately $141 million [20].

[8]In his 1987 Nobel Prize lecture, the economist Robert M. Solow alludes to the growth accounting work of the late Edward Dennison as follows: ''Gross output per hour of work in the US economy doubled between 1909 and 1949, and some seven-eighths of that increase could be attributed to ''technical change in the broadest sense'' … [In] the 30 years since then … [t]he main refinement has been to unpack ''technical progress in the broadest sense'' into a number of constituents of which various human-capital variables and ''technological change in the narrow sense'' are the most important … 34% of recorded growth is credited to ''the growth of knowledge'' or ''technological progress in the narrow sense.'' [22]. Another economist, Edwin Mansfield, has calculated social rates of return on investments in basic research: ''For the seventeen innovations in our 1977 study, the median social rate of return [on supporting basic research] was about 50 percent. For the two follow-on studies, each including about 20 innovations, the median social rates of return were even higher … [T]he social rate of return … was, on the average, at least double the private rate of return to the innovator.'' [23].

and physiology-medicine were 18 out of 26 and 26 out of 26, respectively.[9] The Nobel Prize in economics was established in 1969 and from that year through 1975, six of eight such prizes were either won outright or shared by Americans.[10] With few exceptions, these Nobel laureates were on the faculties of US research universities. As another example, the unique fusion of teaching and research, which was developed in the graduate schools of US universities, provided what has been widely acknowledged as the world's best training for careers in science. During the quarter century following World War II, large numbers of foreign students—for present purposes, students with non-American bachelor's degrees—sought admission to US graduate schools. They still do, although for at least the past 20 years Asians—as opposed to Europeans—have become dominant among them ([11], p. 2–24).

It is useful to note that a good deal of research carried out by university faculty members is conducted in a group of institutions known as Federally Funded Research and Development Centers (FFRDCs), more commonly known as national laboratories, which are fully funded by agencies of the federal government but managed by industrial, university, or non-profit contractors ([25], p. 27–8) Several, such as the Fermi Laboratory near Chicago, the Lawrence Berkeley National Laboratory, and the Gemini Astronomical Observatories in Hawaii and Chile, house big science facilities intended for use by university faculty. The Department of Energy, which funds the two former laboratories and the NSF which funds the observatories provide grants on a competitive basis to facilitate their use. Other FFRDCs such as the Los Alamos, Livermore, and Sandia Laboratories were originally established as nuclear weapons R&D facilities, but have since broadened their activities to include research on environmental and related problems.

One indicator of the importance that the US science and technology system (including its academic component) had assumed following World War II was the creation of a President's Science Advisory Committee (PSAC) and the appointment of a full-time presidential science advisor. Although a recommendation was made during the first months of the Korean War that such an official be appointed, it was not implemented until 1957 ([26], p. 66–7). In November of that year, while the United States was still reeling from the shock of the Soviet Union's launch of Sputnik I, President Dwight Eisenhower designated James Killian, President of MIT, as his science adviser, and within another week named the members of PSAC [27]. In 1962, President John F. Kennedy extended the scope of the presidential science advisory system by creating an Office of Science and Technology (OST) within the White House, naming his science adviser—Jerome Wiesner, Professor of Engineering at MIT—as its director. OST was given responsibility for coordinating the US government's growing science and technology system. Henceforth, presidential science advisers essentially played two roles: an advisory role and a coordinating role.

Significantly, both of Eisenhower's science advisers—Killian and his successor, George Kistiakowsky, Professor of Chemistry at Harvard—and Wiesner all came from research universities. Additionally, of the 17 original members of PSAC, 14 were from research universities. PSAC made a number of important recommendations related to national defense, space and science education. It also issued reports on studies it commissioned, including several relevant to the US research university system [28].

Despite the flowering of US research universities during the decades following World War II, by the end of the 1960s it—and the US science and technology enterprise more broadly—began to be subject to multiple strains. Until the mid-1960s, US industry had few, if any, competitors. But that situation changed as Europe, and then Japan, recovered from the devastation of World War II, and began to flex their industrial muscles. Up to that time, the central proposition of *SEF* continued in effect; if the federal government would support basic research in universities and provide fellowships to train new generations of scientists and engineers, then industry would do the rest. But as American industry began to face increasing competition, questions were raised about whether the support of research universities and fledgling scientists was an adequate science policy for the US government.

With the first stirrings of the environmental movement in the mid-1960s, and the deteriorating situation in Vietnam later in the decade, the mood of optimism that had been so prevalent in the United States following World War II began to fade. The damage to the environment caused, in part, by the inadequate reflection on

[9]Thirty-seven individuals either won the Nobel Prize in Physics outright or shared it from 1950 through 1970. Comparable numbers for chemistry and physiology and medicine were 32 and 44, respectively ([24], p. 282–90).

[10]Eleven individuals either won the Nobel Prize in Economics outright or shared it from 1969 through 1975 [24].

the impact of technology suggested that technology—and the science that underlies much of technology—could no longer be regarded as totally beneficial. A sizeable segment of the anti-war movement held science and technology—and therefore scientists—at least nominally complicit in the devastation being visited upon Vietnam by the US armed forces. Radical students who confronted academic scientists directly (sometimes branding them as war criminals) constituted only a small minority among those who were disillusioned with the Vietnam War. Yet one result of their efforts to accuse science and its practitioners with such complicity was that students who previously had been attracted to careers in science began to look elsewhere ([29], p. 425–32). In the opinion of many scientists, still too few young people, including too few women and members of ethnic minority groups, are pursuing careers in science, although for reasons other than those of the Vietnam era [30].

The federal R&D budget and the component for research universities have grown steadily since 1953, when measured in current dollars. However, when measured in constant or inflation-adjusted terms, both the federal R&D budget and its academically relevant component reached a peak in 1968, then declined until 1974, after which they began to rise once more ([11], p. 4–8). One reason for this decline was undoubtedly the fact that the Vietnam War was draining resources from other sectors of the federal budget, and the US economy, more broadly. It has also been alleged that President Lyndon Johnson, angered at opposition to the Vietnam War on the part of an apparent majority of US university faculty, deliberately punished them by reducing their research support. Certainly Richard Nixon, his successor, was often quite open in his dislike of university faculty and may have deliberately reduced university research budgets as a consequence ([31], p. 244–6).

The decline and fall of the presidential science advisory system in the late 1960s and early 1970s was symptomatic of the strains on the entire US science and engineering system. These strains were experienced by research universities, perhaps more heavily than was true of other sectors of the science and technology system. The presidential science advisory system reached the peak of its influence during the Kennedy administration. Beginning with the first months of the Johnson administration, its influence began to decline until, in the words of Johnson's science advisor Donald Hornig, "it became difficult to get the president's attention." ([27], p. 51). However, Johnson and Hornig did work closely together to negotiate several international cooperative science and technology agreements ([32], p. 66–85). Nevertheless, the president was increasingly alienated from the academic community because of its opposition to the Vietnam War. Moreover, Johnson's domestic signature programs were his Great Society initiatives and he sought advice from PSAC on how to formulate and implement them. But effective advice on matters involving the social sciences was not forthcoming from PSAC, which consisted almost entirely of mathematicians and physical scientists.

The Nixon administration's attitude towards PSAC can be characterized as openly hostile. One member of his inner circle was said to have characterized that committee as nothing more than a lobby for academic science within the White House ([32], p. 55–6). Early in 1973, among his first actions during his second term, Nixon disbanded PSAC and eliminated the position of science advisor held by Edward David.

6. Research universities: 1975–2000

By 1975, what was perhaps the most chaotic period for the United States since World War II had come to an end. With the fall of Saigon during that year, the war in Vietnam was finally over, although the United States had begun to withdraw its troops after the short-lived peace accord signed in Paris in January 1973. In August 1974, Richard Nixon resigned his presidency as a result of Watergate. The new president, Gerald Ford, marked that occasion with the assertion that, "… our long national nightmare is over."

Ford took immediate steps to restore relations between science and government. In 1975, for the first time since 1968, both the federal R&D budget and its academic research component (measured in constant, inflation-adjusted dollars) began to rise once again. Ford also requested his vice-president, Nelson Rockefeller, to convene two non-government advisory committees to explore productive interactions between the academic, industrial, and government research sectors, as well as a means whereby the federal government at all levels could draw upon the advice of the research community. Meanwhile, both houses of Congress held hearings on legislation to revive the presidential science advisory system. On May 11, 1976, President Ford signed into law the Science and Technology Policy, Organization and Priorities Act of 1976 [33] which, among other things, created the Office of Science and Technology Policy (OSTP) within the Executive Office of the President, with the director of OSTP also designated as the president's science adviser ([34], p. 123).[11]

Perhaps the most significant change for research universities during the decade between 1975 and 1985 was a renewal of their support by private industry. Prior to World War II, industrial funding for university research was significant. However, with the seemingly limitless availability of federal funds for academic research starting in the early 1950s, universities increasingly ignored industrial research funding—while companies seemed to have been unwilling to step forward and offer their unsolicited support. By 1975, industrial support for research in universities constituted only 3.3% of the total, while the federal government accounted for 67.2%. Thereafter, industrial support for academic research began to increase, reaching a level of approximately 7% by 1990 where it has remained. In comparison, federal support for research in US universities had declined to approximately 60% by that same year [12].

More important than direct industrial support for university research were federal initiatives to foster research cooperation between universities and industry. In 1978, NSF initiated a pilot program to encourage such cooperation. Although by law NSF cannot provide research support to profit-making organizations, it could and did begin to support universities in their research collaboration with industry. This initial pilot effort proved so successful that additional programs were initiated by NSF, including long-term (up to 11 years) support for two university-based programs: Engineering Research Centers and Science and Technology Research Centers. University–industry research cooperation returns benefits to both parties. From the perspective of private industry, it immerses university faculty and graduate students in matters of particular interest to companies and also helps companies identify promising graduate students that they might hire after those students completed their PhDs.

The incentives for industrial firms and universities to enter into cooperative research agreements were significantly enhanced by the Bayh-Dole Act of 1980 [35]. Prior to passage of this legislation, rights to results from research supported by the federal government had been vested with the government itself. However, the government rarely, if ever, sought to exploit or license research results, including those from its own laboratories. Therefore, potentially useful products and processes that might have been derived from federally funded research were never developed. The Bayh-Dole Act changed that situation. The terms of that legislation granted rights to federally funded research results to the organization that had conducted the research, most prominently universities. Hereafter, private firms could negotiate to share the rights to research results with potential university partners, providing a strong incentive which did not previously exist ([36], p. 407–17).

As research universities became accustomed to working in research partnerships with private industry—and to appreciate the tangible and intangible benefits of such partnerships—they introduced additional mechanisms to profit from promising research results of their faculties. But many individual faculty members started their own companies to develop and market the results of their research. Between 1988 and 2003, US patents awarded to university faculty increased from 800 to 3200 ([11], p. 5–51). Research universities created Technology Licensing Organizations (TLOs) to patent the research results of their faculties and to license those results to private firms. Because the Bayh-Dole Act vests the rights to federally funded research in universities rather than individual investigators, universities instituted their own rules for sharing financial returns from such research with productive faculty members. While not all TLOs make money and only a few make a great deal, TLOs have become crucial organizations by providing a ready means to get university research results into the productive, commercial sector ([11], p. 5–51).

From the outset, the involvement of private industry in academia, as well as the more direct commercialization initiatives taken by research universities, gave rise to concerns. The main concern was that relations with industry would corrupt the fundamental knowledge creation and transmission functions of universities. More directly: there have been concerns that research universities might become "job shops" for industry. If this were to happen, one of the fundamental missions of research universities, i.e. as the sites for

[11]Prior to President Ford's administration, the science advisor was part of the White House staff without a statutory basis. With the 1976 legislation, OSTP was established as a statutory agency and became part of the Executive Office of the President. This distinction has important implications. For example, the science advisor could not be required to testify before Congress as a member of the White House staff, whereas now the science advisor must testify if called upon.

basic research whose results are published in the open scientific literature, would be seriously distorted. This has occurred in some cases when universities conducted proprietary research funded by industry. But overall, universities and their industrial partners appear to have been prudent in recognizing that although academia and industry have different goals, they can arrive at common ground in research cooperation [1,37]. In Europe and Japan, where university–industry research cooperation have also been encouraged with varying degrees of success, similar concerns about maintaining the integrity of university research have been expressed. Significantly, no such concerns appear to have been expressed in China.

Another important NSF initiative during the 1980s was the creation of Supercomputer Centers at five universities, selected on the basis of a nationwide competition that provided state-of-the art computer facilities. Running time at these centers was made available to qualified faculty members who apply for time by means of proposals evaluated in a manner analogous to peer review processes at NSF.

The source of support for R&D, including support for research in universities, has changed significantly since 1975. In that year, the federal government accounted for approximately 45% of total national R&D expenditures, while industry accounted for approximately 42%. In 1979 and 1980, federal and industrial contributions were equal. By 2000, federal contributions had declined to approximately 24% of the total, with industry contributing close to 70%. By 2004, the federal percentage contribution had risen somewhat while that of industry had declined. Whether this is a short-term aberration or a long-term trend remains to be seen [12].

Federal and industrial financial contributions to research in US universities have continued to rise since 1975. Indeed, since then the academic sector has outpaced the industrial and government sectors in terms of growth in the support of research ([11], p. 5–11).

7. US research universities as models for Europe and Asia

By several objective measures, the American academic research system qualifies as the world's best. The number of Nobel Prizes awarded to American research university faculty since 1975 has continued to be greater by far than for scientists in all other countries combined. American research universities and their faculties have also been considerably more successful than their foreign counterparts in commercializing research results. The almost unique system linking education with research in US graduate schools provides students with both a broad base of knowledge in their chosen disciplines, as well as opportunities to learn how to conduct research under the tutelage of world-class mentors. Foreign students continue to be attracted to US graduate schools by the reputation of their faculties. In a study published in 2005, Shanghai Jing Tong University ranked—in order of their excellence—the world's 500 top universities, distinguishing universities in American state multi-campus systems [38]. Seventeen among the top 20 of these universities were American, the 3 exceptions being Cambridge (#2), Oxford (#10), and Tokyo (#20). Of the top 50, 37 were American.[12]

Universities in other countries have attempted to replicate the success of the US research universities but have most often fallen short. American universities are virtually unique in their diversity. They include private universities and those supported by state and local governments; 4 year colleges without graduate or professional schools, as well as 2-year community colleges. The best of these institutions compete with one another for faculty, for students, and for research funds. The country's top universities usually have funds to support the research of newly attracted faculty for perhaps 2 or 3 years. However, the bulk of their research support is derived from grants awarded to individual faculty members or research groups obtained through a competitive process, most often from the federal government, but also from private foundations. In the American system, federal grants are awarded to individual faculty members rather than to the universities themselves. The competition among faculty members for research grants is an important factor in fostering the quality of research in American universities. Few, if any, foreign countries comprehend the intense competition among universities in the United States to move up in the ranking of the country's top

[12]The top 20 universities in descending order were: Harvard, Cambridge, Stanford, University of California-Berkeley, MIT, California Institute of Technology, Columbia, Princeton, Chicago, Oxford, Yale, Cornell, University of California—San Diego, University of California—Los Angeles, and University of Pennsylvania, University of Wisconsin—Madison, University of Washington—Seattle, University of California—San Francisco, Johns Hopkins, and Tokyo.

universities. Or if they do understand, they may be culturally unprepared to engage in such competition ([39], p. 315).

In contrast with the United States, universities in most other countries are components of national systems regulated by a national ministry of education [8,40]. Faculty working in such national systems receive some research support from these ministries as an entitlement. However, funds for reasonably ambitious undertakings are obtained competitively from government or quasi-government organizations often known as research councils. Many of these, such as the Korea Science and Engineering Foundation or the National Natural Science Foundation of China, are modeled on the US NSF. As a member of a national system, regulated by central government authority, it is more difficult for a university to differentiate itself from others and thus to compete effectively.

Reforms and restructuring of public science systems in other countries almost always involve reforms of their national university system. Japan offers an interesting example. The University of Tokyo was established during the 1870s, soon after the 1868 Meiji Restoration, by consolidating and partially westernizing two existing institutions. By the 1920s, nine imperial universities had been established. Seven of these were Hokkaido, Tohoku, Tokyo, Nagoya, Kyoto, Osaka, and Kyushu; the remaining two were the universities of Seoul and Taipei. Following World War II, the latter two institutions were renamed the Korean and Taiwan National Universities, respectively, establishing a basis for the university systems in these former provinces of the Japanese Empire. The other imperial universities became national universities. Many additional national universities were created in all parts of Japan so that by the late 1990s their number had increased to almost 100.[13] Since Japanese national universities are far too numerous to be supported by the country, considerable consolidation has since taken place and is likely to continue.

In 1996, Japan began to undertake major reforms of its government-funded science and technology system, and has been accelerating reforms since 2001. In 2004, its national universities were granted significant autonomy from the Ministry of Education. In particular, they are now free to establish their own curricula and to seek their own competitive niches. Since Japanese university faculty members now are no longer government employees, they are free to engage in research collaborations with industry and seek to commercialize their discoveries or innovations, either through spin-off companies or university-based TLOs [40]. It is too soon to know whether these changes will improve the overall quality of Japanese academic research.

Although only 4 universities on the European continent were among the top 50 in the Shanghai Jing Tong 2005 survey, reform does not appear to have a particularly high priority among European governments or universities.[14] There are several reasons for this. First, several countries have national research institutions that parallel and in some respects compete with their research universities. Examples include the Max Planck and Fraunhofer Institutes in Germany, which emphasize basic and applied research, and the laboratories of the National Council for Scientific Research (CNRS) in France. The situation in France is further complicated by the existence of the Grandes Ecoles, including the Ecole Polytechnique, whose graduates are accorded considerably more prestige than the graduates of French universities.

A more important reason why the reform of individual universities and national systems on the European continent may not have a high priority is due to the resolve of the European Union (EU), first articulated in 2000, to establish a European Research Area "… by creating a joint dynamic for research and development (R&D) and increasing expenditure to make the EU 'the most competitive and dynamic knowledge-based economy in the world'" [41]. Although the goals of the European Research Area initiative are still far from being realized, the EU has had considerable success in programs such as *Socrates* and *Erasmus* intended to promote the mobility of students at the undergraduate and graduate levels among universities in member countries [42]. These programs have had the effect of creating a virtual Europe-wide university system with individual universities and national systems competing for the best students. An additional contribution of the

[13]Unlike European countries, Japan also has a number of private universities, several regarded as outstanding. Many of these have better records of cooperation with industry than Japan's national universities, although the record of several, including Tokyo, Kyoto, and Tohoku has been improving.

[14]These four universities are The Swiss Federal Institute of Technology, Zurich (#27); the University of Utrecht (#41); Karolinska Institute, Stockholm (#45); and University of Paris 06 (#46) ([11], p. 5–51).

EU has been to adopt uniform standards for various professions among member countries. For example, an individual with an engineering degree from an Italian university is now eligible to apply for, and receive, a license to practice engineering in Germany.

Although the EU has consciously modeled its research programs after those of the United States, its European Research Area initiative is intended to make it more competitive with the United States and, to a lesser extent, with Japan. By some measures, it has succeeded in this. For example, since 1993, the publications of EU authors in international peer reviewed journals has exceeded that of the United States, and the gap has been growing. In 2001, authors at institutions within the EU accounted for slightly more than 33% of all such publications, while the share of those by authors at US institutions was slightly less than 29%. The EU, however, is somewhat weak in technology research as measured by the volume of R&D expenditures by private industry and the share of patent applications filed ([8], p. 88–90).

China provides a more recent example of a series of attempts at university reform. Chinese universities created on a Western model emerged in the late 19th and early 20th centuries. Like other Chinese institutions, its universities suffered during the chaos that followed the collapse of the last imperial dynasty in 1911, the subsequent warlord period, and the years of Japanese occupation. The Peoples' Republic of China, founded in 1949, adopted the Soviet Union's model for its research system. This meant that virtually all research was conducted in institutes of the Chinese Academy of Sciences—created within a year of the founding of the Peoples' Republic—and universities became almost exclusively teaching institutions. The curricula of universities were prescribed by the Ministry of Education, as were the disciplines they could teach. For example, Peking University was assigned to teach subjects such as Chinese classical studies and law, whereas nearby Tsinghua University was to specialize in engineering.

Following the reform and opening of China initiated by Deng Xiao Ping in 1978, the country's research and higher education system was modified. In particular, universities were permitted to broaden their curricula, and the best began to conduct research. Several Chinese universities including Peking and Tsinghua have created graduate schools on the US model in which students are required to take advanced courses and pass qualifying examinations before initiating research towards their dissertations [43].

The National Natural Science Foundation of China, modeled on the US NSF, was created in 1986 to provide competitively based research grants to university faculty. One of China's goal is to increase the number of its world-class research universities. Perhaps as many as 10 or 12 such universities led by Peking and Tsinghua qualify [44]. It remains to be seen whether the Chinese university system, still under considerable government control, can become internationally more competitive ([45,46], p. 187–93). An interesting and continuing debate centers on the extent to which Chinese universities must adopt a Western, or more to the point, an American model if they are to become "world class." It is worth noting that at least two-thirds of the research conducted in China's academic sector is still performed in the institutes of the Chinese Academy of Sciences. Since the 1980s, the Academy has instituted its own graduate school very much on the American model [11].

8. US Research universities today

In 2004, industry provided a total of approximately 62% of total national R&D expenditures, a decrease from 68% in 2000, while the federal government provided approximately 28%, compared with 22% in 2000. These percentage changes were due primarily to decreased R&D investments by industry; whether they represent a trend or are short-term fluctuation remains to be seen. In 2004, the US academic sector accounted for 13.6% of all R&D performed in the country. The share of total R&D support to US colleges and universities had risen steadily from 5.3% in 1953, to 10.0% in 1975, to 11.0% in 2000. Of the $42,431 billion in research performed by the US academic sector in 2004, 61.5% was provided by the federal government, 19.3% from the institutions' own funds, 9.0% by private non-profit organizations, and approximately 5% each by industry and special state government programs [12].

According to the Carnegie Foundation for the Advancement of Teaching [47], in 2006 there were 4387 institutions of higher education in the United States, including such organizations as stand-alone professional schools, business schools and bible colleges. Among these, 1811 were 2-year associates-community colleges. The Carnegie Foundation classifies institutions as research universities based on several variables including the number of advanced degrees granted and federal research funds received. Research universities that have a significant level of research activity fall into two categories: RU/VH (Research Universities/very high research activity) and RU/H (Research Universities/high research activity). There are 96 institutions categorized as RU/VH and 103 as RU/H for a total of 199; thus, among all institutions of higher education 4.3% are engaged in a significant measure of research.[15] Approximately one-third of these research universities are private and two-thirds state-supported.

In 2003, the top 100 research universities, ranked in order of their research expenditures, performed 79.6% of the total research carried out by US universities; the top 20 carried out 29.6%; and the top 10, 16.9% [48]. Among the top 20, 12 were state-supported institutions, and 8 private institutions.[16]

Despite these gross, largely positive, indicators of the state of US research universities, the academic sector (as well as the individual institutions of which it is comprised) faces a number of problems, some of them critical ([49], p. 22–31). Increased funding for academic research has continued to be skewed towards only a few fields. Between 1973 and 2003, support for medical sciences (measured in constant, inflation-adjusted dollars) rose from approximately $3 billion to $12 billion, that for biological sciences from slightly less than $3 billion to $7 billion, while support for engineering research in US universities rose from $1 billion in 1973 to approximately $5.6 billion in 2003. In contrast, support for most other academic research disciplines, including the physical sciences, the earth, atmospheric and ocean sciences, and the social sciences, increased from about $1 billion in 1973 to about $2 billion in 2003 ([11], p. 5–12:13). As frequently remarked, it is easier to convince members of the US Congress to support health-related research than research in other disciplines.

The skewing of federal research funds has been exacerbated to some extent by the practice of earmarking congressional appropriations bills by members of both the House of Representatives and the Senate to provide funds for universities in their congressional districts or states—most often for a new building to house a recently created research institute. Although the annual total of such research-related earmarks is small compared with congressional earmarks for bridges, highways, libraries, or hospitals, such earmarking circumvents the peer review process which is a cornerstone of the research university system. Moreover, there is no evidence that a new building or research facility earmarked for a given university has led to its becoming more highly regarded. Entry into the ranks of leading research universities is a long and arduous process that cannot be short circuited by congressional earmarks.

One problem faced by research universities is the inordinate amount of time that faculty members, particularly younger ones, are compelled to devote to proposal preparation. As already noted, many research universities provide start-up funds for new faculty, including young faculty, to equip their laboratories and conduct initial research. After that, they are expected to obtain research support from external grants, most often from a federal agency, but sometimes from industry or a non-profit philanthropic organization. During recent years, funds for academic research in many fields, including mathematics, the physical sciences, and the social sciences, have increased very slowly, when measured in constant dollars. As a result, competition for federal research funds has become formidable. For example, the overall success rate for proposals submitted to NSF is approximately 30%; the success rate for proposals from newly appointed PhDs is closer to 20%. Unless junior faculty members can obtain research funding during the first 3 years of what is normally a 5-year appointment and demonstrate that they can produce acceptable research, they are compelled to seek appointments at less prestigious universities—or abandon academic research and seek careers elsewhere, often in industry. Although such mobility can be positive both for individual researchers and for the strength of the US science and technology enterprise, it also can be regarded as a waste of talent among gifted young faculty. On a more positive note, industry and other organizations have been welcoming qualified PhD recipients. These include not only traditional manufacturing companies, but also investment firms, banks, financial

[15]The Carnegie Foundation has a third category called Doctoral/Research Universities which includes 84 institutions. However, the overall level of research at these institutions is below the standard for research universities as the term is used in this paper.

[16]The top 20 in descending order were: University of California, Los Angeles; University of Michigan, all campuses; University of Wisconsin, Madison; University of Washington, Seattle; University of California, San Francisco; University of California, San Diego; Johns Hopkins University; Johns Hopkins University Applied Physics Laboratory, Stanford University, University of Pennsylvania; Cornell University, all campuses; Pennsylvania State University, all campuses; Duke University; Texas; A&M University, all campuses; University of Minnesota, all campuses; University of California, Berkeley; Ohio State University, all campuses; University of Illinois at Urbana—Champaign; and Massachusetts Institute of Technology and University of California, Davis ([49], p. 22–31).

institutions, as well as national and state government agencies. For their part, PhD recipients working in such organizations often relish the opportunity to do "real work."

A related problem faced by American research universities is that in an effort to compete more effectively for scarce research dollars, faculty members often opt to submit proposals for "safe" research projects rather than more risky ones that might lead to major breakthroughs. As a result, too many research papers published in the scientific literature are mediocre at best, serving little purpose other than to increase the publication lists of their authors.

Another problem is the protracted length of time required for new PhDs to obtain tenure-track appointments. Today, a minimum of 5 years is required for students in the natural sciences and engineering to obtain their PhDs, with 7 years being the norm. After that, new PhDs in many fields take one or more 3-year post-doctoral appointments before they can be considered for tenure-track appointments in a leading American research university. As a result, young scientists typically are in their mid-30s before their independent scientific careers can begin. Meanwhile, many of their undergraduate classmates have obtained secure positions in other economic sectors, not to mention enviable salaries. Such conditions are hardly conducive to attracting talented young Americans to careers in science. American universities have long relied on foreign-born graduate students to conduct much of the research initiated by their senior mentors, thus maintaining the viability of graduate schools in science and engineering. Between 1983 and 2003, the number of foreign graduate students enrolled in US research universities rose from 70,000 to 130,000, or from 19% to 27% of total graduate school enrollments. Although there was a slight decrease in these numbers due to stringent visa requirements instituted after September 11, 2001 their numbers have started to rise again ([11], p. 2:23, 2:24).

In engineering, computer science, and the physical sciences, over 41% of all graduate students at American research universities are foreign born and reside in the United States on temporary student visas. Among these students, in 1999, 33,000 and 23,000 were, respectively, Chinese- and Indian-born ([11], p. 2–24). Many of them have made outstanding research contributions while studying at American universities. This emphasizes the significance of the American research university system in opening up paths to citizenship for foreign students educated within that system. As a "nation of immigrants" the United States has been able to integrate these foreign-born students into its science and technology system, an accomplishment of which few other nations can boast. Some have gone on to assume faculty positions and/or contributed to innovations in US industry—in Silicon Valley, for example. However, there is no reason to believe that the numbers of these indispensable foreign students will continue to increase indefinitely. In 1998, Asian institutions of higher education awarded 20,000 PhDs, on a par with the number awarded to Asian students in the United States, and the number of PhDs awarded in Asia continues to grow. In many instances the increase in the number of PhDs awarded in Asia has been matched by a concurrent increase in the quality of graduate education in leading Asian universities. As a result, since 1995, a growing number of Chinese, Korean, and Taiwanese students have been obtaining their doctoral degrees at universities in their home countries rather than in the United States or other favored destinations such as France, the UK, or Australia [25]. In view of the dynamic rise of Asian countries and their determination to move their universities into the ranks of world-class institutions, American research universities would be ill advised to rely indefinitely on students from Asia to populate graduate programs and their faculty.

On a positive note, US universities are making it easier for non-American students to study and conduct research by establishing their presence abroad. According to Johns Hopkins president William R. Brody, his university has more than a dozen campuses in the United States and research projects in 80 countries. As another example, the University of Maryland has a business school with programs in nine locations on four continents, including campuses in Beijing and Shanghai [50].

A problem facing US research universities is a consequence of their phenomenal success. As research has advanced, it has also become increasingly specialized so that many university departments, whose faculties conducted research in a number of sub-specialties, have fragmented into independent departments each devoted to one of these sub-specialties. Moreover, many universities that were once primarily institutions with a core college of arts and sciences plus a few professional schools such as law and medicine, now include less "academic" schools devoted to what are considered more "practical" curricula. While in itself this may not be a problem, it has led to further fragmentation of research universities [47].

Although rhetoric abounds about the integrated roles of universities in research, teaching, and public service, faculty advancement still depends heavily upon research—including the ability to attract research funds with overhead budgets essential to university operations. University faculty usually treat their graduate students reasonably well, in part because they depend on them to staff their various research projects. Undergraduate instruction is often treated as peripheral to faculty interest. Undergraduate courses in research universities usually consist of two or three lectures per week by a senior professor to a large roomful of students, followed by recitation sections led by graduate students or post-docs with minimal teaching experience—many of whom are foreign students with only halting English and no appreciation of the give-and-take between teachers and students that is commonplace in US colleges and universities. Indeed, it is worth noting that a larger proportion of undergraduates who attend high quality 4-year colleges go on to study at graduate and professional schools than do those who are undergraduates at the country's leading research universities ([11], p. 10–2). However, in recent years, undergraduate education has become a focus of attention for research universities and considerable progress has been made in the quality of instruction.

For the past two decades, NSF and other federal agencies, in concert with professional science and engineering societies, have mounted major programs to convince more women and ethnic minorities to seek careers in science and engineering. The results of these programs have been disappointing. The one impressive result has been a noticeable increase in female engineers. There have also been slight increases in the number of females who elect to obtain PhDs in the physical sciences. However, there is indisputable evidence that many of these talented female PhDs encounter the proverbial ''glass ceiling'' as they attempt to advance in the conservative, slow-to-change academic hierarchy [51].

A problem unique to state research universities is the dependence of their budgets on the changing whims of state governors and legislatures. Although leading state universities derive the bulk of their research budgets from federal grants, funding from state governments remains the bedrock of their research programs. While one state governor and state legislature may recognize the importance of the research and educational offerings of their university, their successors—faced with budget deficits—may decide that significant reductions in university budgets can do little harm in the short run. They fail to understand that reconstituting a diminished educational institution takes many years to accomplish.

Research universities in the United States are fundamentally conservative institutions. When they do change, they most often do so slowly and deliberately. The evolution of American colleges into research universities proceeded slowly following the Civil War. Only during the past 60 years have those universities flourished and become the core of the US science and technology system. Clearly, US research universities cannot afford to rest on their laurels or assume that the public understands and appreciates the essential role they play in the furtherance of society's fundamental goals. The quality of the research and teaching provided by East Asian universities has been rapidly improving during the past few years. As in other regions of the world, these universities, particularly in China, aspire to become competitive with universities throughout the world—particularly with universities in the United States—and may achieve considerable success.[17] However, the record of the past 60 years suggests that US universities can continue to compete successfully in the world market for knowledge. But they can do so only if they, and the wider US public, understand the challenges they face and are prepared to accept them.

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