The Competitiveness of U.S. Research Universities

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The Washington Advisory Group, LLC

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Definitions of Research and Development

In this report, the terms "research" and "fundamental research" are used interchangeably to denote the scope of activities delineated as "basic research" and "applied research" in the statistical charts and accompanying text in Section IV and Appendix I. These quantitative materials and the related discussion use the following official U.S. federal government definitions designed to be consistent with international definitions:

- **R&D** (or "total R&D") refers to both the conduct of research and development as well as R&D facilities. R&D is performed for the purpose of "increasing the stock of knowledge, including knowledge about humanity, culture and society" (Organisation for Economic Co-operation and Development (OECD) 1994).
- **Research** is systematic study directed toward fuller scientific knowledge or understanding of the subject studied. The federal government categorizes research as either basic or applied according to the nature of the work and the outcomes.
- In **basic research**, the objective is to gain fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts.
- In **applied research**, the objective is to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.
- **Development** is the systematic application of knowledge or understanding directed toward the production of materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements.

Academic R&D activities are concentrated at the research (basic and applied) end of the R&D spectrum and do not include much development activity. The inverse is true for industry R&D expenditures: industry primarily funds development efforts, and provides a lower level of funding for applied and basic research. However, the term "R&D" (rather than just "research") is usually used with reference to funding statistics because the data collected often do not differentiate between research and development or it is difficult to make clear distinctions among basic research, applied research, and development.

III. Introduction

The Washington Advisory Group was engaged to examine the following:

A. What factors make U.S. universities competitive, particularly as contributors to industry and the U.S. economy? The study sponsors recognize that the United States' economic strength, especially that stemming from innovation, derives in part from the excellence of its universities in research and development (R&D) and education. The main part of this report will deal with this important question.

B. A separate contract by the study sponsors asks the Washington Advisory Group to analyze and breakout the sources of funding for university research, including the opportunities and liabilities that this support entails. Appendix I deals with this contract and question, although the main part of the report also includes comments and observations about this vital and complex issue.

This study is designed to identify and examine not only those factors that have fostered such successful competition, but also those drivers that have changed the values, culture, and behavior at U.S. universities and motivated the interest in this study.

The economies of nations have become increasingly dependent on science, technology, and the commercialization of research outcomes. For this reason, U.S. research universities play a pivotal role in the country's economic vitality. This study examines the complex processes by which these universities achieve such results and maintain a competitive edge. In doing so, it seeks to increase our understanding of how they contribute to a healthy economy and strong economic development, and how they can continue to do so. It also provides an overview of the R&D university system in the United States, with emphasis on those changes over the past five to 25 years that prompted and reinforced increasing competition to achieve excellence. The report focuses especially on fields in which the U.S. is an acknowledged leader, namely electronics, information technology, and biotechnology, as well as business management as it relates to corporate strategy, entrepreneurship, and financial market developments.

This study also examines the missions and characteristics of research universities, both public and private, as well as the goals and strategies they pursue to maintain or increase their competitiveness. In this context, this report examines such issues as governance; student body selection and composition; faculty recruitment, incentives and promotion; infrastructure (facilities and instrumentation); economic contributions; funding mechanisms; and institutional and personal recognition and prestige. The report also identifies criteria for success as well as incentives and disincentives for attaining such success.

Case studies of specific universities round out this comprehensive phase of the analysis. The selected universities—Massachusetts Institute of Technology (MIT), Stanford University, University of Texas at Austin, and University of California, San Diego (UCSD)—are examples of institutions that have top-ranked research programs, particularly in the key disciplines of information technology, biotechnology, and the relevant business management areas. While some of these institutions have long been recognized as top research institutions and have led others in recognizing and responding to the challenges of a competitive environment, others have more recently emerged as leaders. Relatively long-term and newly emergent leading institutions demonstrate how research universities can attain strong staying power or build excellence and renown. These case studies therefore review and summarize the strategies both types of institutions use to maintain and enhance their competitive edge.

Lastly, the study analyzes the funding sources and trends for U.S. research universities, including how budget changes and legal/regulatory influences affect university policies and practices. This analysis highlights the opportunities and liabilities such support entails, as well as the impact that shifting funding sources and allocations can have across various research disciplines. Commensurate with our contract with the study sponsors, this report deals exhaustively with this issue in Appendix I, as mentioned above, but for completeness also explores it within the main report.

II. Research Universities

This section describes the common attributes of U.S. research universities and the environment in which they operate, as well the state of the institutions and the outlook for the near future.

1. The System of U.S. Research Universities

The research university in the United States has the joint mission of offering undergraduate and graduate education and linking this education to research in the life and physical sciences, biomedicine, engineering, social sciences, and humanities. The U.S. has some 200 such research universities. In contrast to the long world history of universities, this system[1] of research universities is no more than 50 years old. It is, however, unique in size, scope, diversity, and accomplishment. Despite numerous stresses generated by old and continually emerging problems, the system is also sound and resilient, and fulfills the dual role of training the next generation of scientists and engineers and others in their diverse careers including management, arts, humanities, and others, all in the interests of maintaining the position of the U.S. as a world technical and scientific leader. As this report will make clear, the system also faces serious problems and can be improved.

2. Environment and Characteristics of the System

The following attributes are the most distinctive features influencing the operation, reputation, and perception of U.S. research universities. These features also continue to play a major role in determining the direction of the entire system.

Science is recognized as a public good: Federal and state agencies, industrial leaders, philanthropic foundations, the media, and the public generally recognize[2] the important part that university research—and the related training of scientists, engineers, and managers—have in economic growth,[3] national security, public health, and national prestige. Financial support, for example, reflects this view: For the past 20 years, allocations for academic R&D from federal

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[1] We will refer to the aggregate of U.S. research universities as the system.
[2] For example, congressional initiatives to double the research budget of the National Institutes of Health, National Science Foundation, and support for Department of Defense scientific research.
[3] For example, more than 60 percent of publications cited in industrial patents refer to academic papers, mostly the result of government-financed research.

and state governments, industry, and all other sources have each increased steadily. Federal support has remained the largest portion, and has grown from some $6 billion to $16 billion in constant dollars.

Peer review of faculty proposals: Federal research grants to university faculty engaged in scientific or technological research are typically awarded to an individual or a research group, with the institution playing a legal and pro-forma role. Since these awards are the largest source of funds available, the allocation process is crucial to the success of American research universities. The allocation is an open competition in which experts in the field (peers) evaluate research proposals. This peer-review process is generally honest and fair, and funds the best research proposals. Nor is faculty rank a factor in the process; indeed, Nobel Prize winners have been known to lose out to assistant professors.

Allocations to individuals and groups rather than institutions: Faculty members of all ranks can apply for research grants as independent scholars, with funds allocated based on peer review to individuals or groups of researchers, rather than to the institution in which they reside. In fact, if the principal investigator, also referred to as a PI, transfers to another institution, typically the related funding also transfers with him or her.

No favoritism: As the use of peer review suggests, no established hierarchy within the system and no policy favors a select group of universities over all others. An institution's prestige may therefore rise and fall in the eyes of its peers and the public in a relatively short period, but the system's upward trend in quality should persist.

Competition for outstanding faculty; promotions based on creativity and productivity: On occasion, the competitive environment noted immediately above does lead to what could be considered extreme salary offers and can generate bad feeling between research institutions. Overall, however, competition promotes the careers of the most talented individuals and, because their growing stature tends to bring them additional resources, makes them more productive than they might otherwise be.

Accessibility: Despite the competitive nature of the funding and research process, the system is characterized by sharing of research results and openness of communication among students, faculty, and research sponsors. This attribute tends to ensure that the system and its research efforts benefit to the maximum degree from individual advancements or discoveries.

Faculty consulting for industry: In the top research universities, a significant percentage of science, engineering, economics, and business school faculty consult for industry up to the official limit of one day per week. Just as the accessibility mentioned immediately above promotes the sharing of ideas, this freedom of consulting helps effectively transfer technology between the system and industry.

Mobility of faculty within the system: The openness to sharing of ideas and consulting also emerges in faculty mobility. It is not uncommon for a faculty member to move one or more times to other institutions as he or she progresses up the academic ladder. Such mobility defeats provincialism, and brings fresh views to a campus. These and other advantages outweigh the related problems of inefficiency and waste that can emerge from loss of personnel.

Diversity: Faculty and student populations are rich in diversity. They also come from domestic and foreign sources; in fact, talented immigrants, visitors, and temporary assignees compensate for domestic shortages in some fields. Faculty and students also come from a small but increasing pool of U.S. minorities, African-Americans, Hispanics, and Native Americans. Gender distribution also has become more balanced than previously, especially in the life and physical sciences and engineering, which had attracted a rather low percentage of women relative to the population at large.

Student recruitment and graduates: The competition for top students has grown over the years. Active recruiting of students with credentials indicating likelihood of academic success has now become fierce among the desirable universities. Alumni, faculty, and even graduate students recruit high school students with strong test scores and grades, as well as those who excel in extracurricular activities. In many instances, students invited to matriculate have a choice between contending institutions, and further incentives emerge for those accepted to enroll. Inducements can include scholarships, exemption from certain fees and costs, and other financial assistance.

The same competitive process applies to the recruitment of undergraduates for graduate programs. In recent years, the best universities have considerably increased funding available for fellowships for these candidates. One important reason for this particular level of competition is that graduate students in the research phase of their training are working scientists who can significantly increase the research productivity of their professors.

Such focused recruitment efforts do not, though, diminish the scholarly effort required of students once they enroll. A research university's primary product is its graduates, and the excellence of graduates plays a major part in distinguishing among institutions. Universities thus take unsparing efforts to assure the quality of enrollees as well as of students achieving degree status. Universities also now make these efforts with due consideration of the need for social, racial and gender balance in the student population.

Mirroring the competition among universities for students is the competition for graduates among corporations, governments, and universities themselves. All such organizations have programs to identify outstanding graduates who can be recruited as employees.

Defined roles of board, president and faculty: As will be substantially elaborated upon in the next section, institutional governance typically rests with the board of trustees, management with the president and administration, and academic research choices and educational policies with the faculty. This tri-partite structure is mutually understood and recognized as legitimate across the system, and has proven its value in giving everybody a voice in developing mutually agreed-upon strategies and policies for the respective university.

Reasonable and felicitous government policies for the system: Although not without controversy, the system's governance, management, and intellectual activities are largely independent of other influences. Felicitous regulation that assures this independence includes rules that assign to universities patents stemming from federal research investments; permit summer salaries to researchers from federal grants; and allow library budgets, new construction, and other university expenses to draw on the indirect funds typically attached to government grants.

Research centers: As science and technology evolve, new research subjects emerge. The universities often handle these opportunities not by adding new departments, but by establishing research centers focused on new subjects. This approach to new research prospects originated during World War II, when interdisciplinary efforts proved essential to the development of radar and electronic weapon systems. The centers assure integrity of purpose as well as defined missions that serve specific institutional objectives. Typically, the centers also play an important role by encouraging cooperative research across the disciplinary lines of academic departments. By doing so, they strengthen the contributions of academic research to interdisciplinary research, commercial activity, and graduate education. In this way, the centers have been able to enhance, rather than diminish, the importance of individual faculty, research fellows, and academic disciplines and departments. Federal programs, augmented by state and university funds, usually fund these centers. The National Science Foundation (NSF) in particular has been successful establishing its Engineering Research Centers (ERC's) and Science and Technology Centers (STC's) within the system.

3. Concerns and Trends

Thanks to the above attributes of the system, research universities have evolved to become extremely competitive, independent, and highly responsive institutions. Yet, despite having been identified for many years, a series of problems and concerns have persisted that hinder the system and its ability to fulfill its potential as a force for education, research, and development. The most considerable of these problems and concerns are the following:

- Individual faculty members are under constant tension writing proposals for research grants to support their research team, all the while knowing that the success ratio is perhaps one in three. Rather than accept this life style, many talented people do not enter the system, depriving it of tremendous human resources.
- University officers must justify to federal accountants, who may have limited knowledge of how research is conducted, the rationale for and amount of indirect cost recovery, cost of overhead, and other expenses associated with research expenditures of government funds. As a result, research universities devote considerable time and expense to answering questions and providing justifications that may not always be necessary, and

individual faculty face impedances to carrying out their work with the best possible level of support and focus.

- Science and engineering faculty members, drawn together by research interests, tend to show more loyalty and involvement with distant colleagues in their discipline than to their local campus associates. Such a circumstance detracts from the discourse, interaction, and sense of community that are essential elements of a university.
- The occasional researcher who falsifies, fabricates, plagiarizes, or otherwise violates the basic values of science erodes the credibility of the system. The reputation and support given the system remain vulnerable in such ways to individual actions.
- Despite the great value of peer review, many panels that evaluate and recommend proposals often are so conservative that they do not support interdisciplinary or unconventional proposals. It must be noted, however, that a better system than peer review has yet to be found, and the process has undoubtedly contributed to U.S. leadership in many fields of science.
- While, as will be discussed, the growth of industry-sponsored research has been crucially important to the increasing contributions that universities have made to their states, regions, and the nation, these deepening alliances do raise challenging questions related to conflicts of interest and institutional ethics that must be addressed to insure the continued integrity and credibility of the system.

Meanwhile, other trends that could be damaging to the system have also appeared or strengthened in recent years and must be noted:

- Concern about international terrorism, if carried too far, could reduce the culture of openness that has so benefited the system. Such concerns could also hinder the tradition of providing foreign students and academics access to U.S. research universities. Both results would reduce research productivity and shrink the pool of available talent.
- The recession will seriously reduce the system’s income, particularly due to economic declines, rising budget deficits at the federal and state levels, decreases in philanthropic

foundation endowments, and reductions in industrial profits. Many states also face economic decline even beyond the current recession. In addition, imports are increasing, and manufacturing jobs declining. These financial stresses occur at a time when access to state-of-the-art facilities and equipment has led researchers to anticipate discoveries of unprecedented importance and enormous consequences for the public good.

- Pressure to introduce performance standards and output measures of research are growing even though no agreed metrics exist for assessing research in this manner. If unwise choices of metrics are made, the system will suffer.
- Many grants are too short in duration, in some agencies no more than one or two years. This is too brief for advancement of many research efforts and requires the frequent expense of substantial time and effort to renew proposals.
- Legislators sometimes circumvent the peer review process and mandate that funds be awarded to a specific institution. Academic strongly resist such politically motivated allocations, known as pork barrel, because they are neither objective nor based on quality, as peer review is. Further, these appropriations undermine a key reason for the success of the system and reduce the funds available for unfulfilled research needs that are being competitively pursued. For now, these political allocations remain a small percentage of the total, but it is of great concern that they are increasing.

It is also worth noting that negative trends are not the only ones affecting the system. Another series of trends could well prove positive to the system's long-term strength and value. The most important of these promising trends are the following:

- Governors have come to appreciate research universities as forces that draw knowledge-intensive industries into their states. States that have reaped economic regional benefits from their universities, such as California, Massachusetts, North Carolina, and Texas, serve as role models for other states. As a result, across the country, governors have introduced programs of financial support for professor-entrepreneurs, tax incentives for new companies, incubators for growing new companies beyond the laboratory stage, and other incentives. This positive development, however, will be qualified by the inability of some states to attract firms from among the limited industrial opportunities.

- The federal government has doubled the National Institutes of Health's (NIH) research budget over the past five years. This is a positive signal for the biomedical sciences, a key growth area for both health and economic reasons. At the same time, an imbalance has resulted between these sciences and the physical sciences and engineering. To rectify the situation, pressure has grown to provide NSF with the same increases in federal support over the next five years as the NIH has recently enjoyed.
- Support from the federal government has led to an increasing number of university consortia that partner in building multimillion-dollar research facilities requiring expensive equipment and maintenance support.
- Universities are improving their performance in transferring technology to industry. As a consequence, university income from licensing is increasing.

III. University Operation and Organization

As the above material indicates, the U.S. research system benefits from diverse strengths. From its openness to its management structure, the system has developed a set of attributes and processes that should help it surmount the challenges it faces, including certain problematic trends. In meeting these and other challenges, each institution will depend in particular upon its internal structures. This structure plays a vital role in a university's stature, responsiveness to change, and lasting success. We therefore will review carefully how the system has evolved, and the institutional operation and organization that now shape it.

1. Role and History

Multiple responsibilities, goals, constituencies, funding sources, and competitors influence U.S. research universities. The most successful institutions have made significant choices between these forces, and have carefully selected over the years certain fields and missions in which to excel. These choices have guided institutions in assigning priorities, developing funding, and recruiting faculty and students to undertake the most important teaching and research tasks. Institutional success in fact ultimately depends upon how well an institution identifies these tasks, allocates its resources, and performs its assignments.

The role of universities expanded dramatically during the 19th and 20th centuries. In the 19th century, the major transformations were the growing secularization of private universities and the widespread creation of state universities. The curriculum also expanded and became professionalized, particularly because of the Morrill Act of 1862. This federal legislation not only led to the creation of public land-grant universities, but also ultimately increased the role of universities within each state, including in extending knowledge, delivering professional training, and providing technical advice to farmers, farm families, and others who could benefit from faculty expertise.

In the 20th century, universities underwent these five major transformations:

- They became the gateway to, and the foundation of, most professions. In large part because of the work of professional schools within universities, new professions and services actually emerged, ranging from architecture to management to public health.
- Universities became significant agents of social mobility, growing in inclusiveness and providing a means for economic advancement to many types of people previously denied access to university admission.
- Universities expanded their research and scholarly activity to an extraordinary extent, becoming in effect the agents of research in the United States. This expansion has given universities growing influence on the spectrum of disciplines, professions, and service activities.
- Universities had an increasingly consequential impact upon their neighboring regions, mostly because of their contributions to education, training and research. Regional universities, for example, have influenced not only professional employment and economic development, but also almost every area of society. Largely as a result of university-industry cooperation, certain areas even spawned new industries, such as in Austin, Texas; the Research Triangle of North Carolina; and Silicon Valley in California.
- Universities expanded their range of services to include social programs, such as model schools and legal aid clinics, agricultural research and advice, hospitals, dental clinics,

public health outreach, and economic development. This service and research have become entrenched in many local communities and in others assumed a regional or even statewide impact. In a few cases, neighboring states cooperate in delivering such programs. In other cases, universities sponsor international activity of this kind on a substantial scale.

Such changes in function have increased the size and complexity of individual institutions as well as of the system as a whole.

2. Governance and Management

Governing universities entails different responsibilities than managing them. Governance involves defining and approving the mission and goals of the institution, overseeing its resources, approving its policies and procedures, appointing its president, and, in general, supervising and protecting both the institution and its members. In contrast, management involves effectively operating the institution and achieving its goals within the context of the policies and procedures that the board of directors or trustees has approved. Management also entails effectively using resources; supporting creativity, teaching, research and service; and maintaining the highest standards of scholarly integrity and professional performance.

Governance typically rests with a board of trustees. Board members, who in some institutions are instead called governors or regents, are representatives of society at large. They guarantee public accountability for the actions of the university, and defend the autonomy and distinctive role of the institution. The board enjoys substantial authority, especially in private universities. Many states also have statewide boards of higher education, which are responsible for developing policy and overseeing the universities.

Beyond appointing the president, the board of trustees also monitors, evaluates and supports the president, and insures the availability of resources to carry out the mission of the university effectively and to achieve the particular goals it has established. Normally, the board of trustees also approves all tenured appointments to the faculty, confirms appointments to the executive staff, reviews and approves the budget, controls the management of the endowment, approves policies and procedures that are campus-wide in application, develops a campus facilities plan, approves all major construction and renovation, and approves all new programs, centers, divisions, and departments.

Although most of these functions involve approval, rather than the initiation of a new policy, such approval requires general comprehension, oversight, professional knowledge, and careful review from trustees.

3. Size, Appointment, and Composition of the Board

From institution to institution, boards of trustees vary widely in numbers of members and the background of the individuals appointed. In general, boards of trustees—or regents/governors—in public universities tend to be smaller than those in private universities, largely because the boards of private universities are intimately involved as interested representatives of the university in fundraising and other activities. A typical public university board may have from eight to 16 members. In some cases, the president of the university serves as chairperson of the board; in other cases, a separate chair exists and the president is an *ex officio* member. In private universities, boards can range from about 20 to 60 or 70 individuals. In such cases, much of the detailed work of the board is delegated to standing committees of the board.

Boards tend to draw their membership from men and women who have earned a degree of recognition, access, and influence through success in their chosen fields or professions. This background, often in the world of business and professional practice, serves them well in establishing the strategic framework and goals of the university, and in evaluating the performance of its leaders.

Boards of many public universities also include representatives of both the faculty and the undergraduates, who have the same rights as any other board member, thus broadening the public representation of the board. These individuals are generally elected by faculty or chosen by the students, respectively.

Appointment of all other members to the board in public universities is either on the recommendation of the governor, typically with approval by the state senate, or, in a few instances, such as the State of Michigan, by statewide election. Most universities have a single board of trustees devoted to them; in other cases, a single board of trustees governs affiliated university campuses. Terms of appointment vary, usually from four to eight years, with a possibility of one-term renewal at the end of that period. Board officers generally are exempted from the limitation of two terms of service.

In most private universities, boards are self-selected. They consist chiefly of alumni, but other individuals also serve useful roles. The board elects its officers, who generally serve for fixed appointments of two, three, or four years. A full-time professional typically fills the position of secretary of the board. In a relatively few cases, representatives of the student government, faculty government, and employee government also serve as members of the board.

For public universities, state laws require that meetings of boards of trustees be open to the public. In limited cases, the meetings may be closed, especially when dealing with personnel matters, real estate, or legal issues. In private universities, board meetings are not open to the public, though sometimes board members will receive public delegations and hold sessions for community input.

In the case of most small boards, which exist primarily in public institutions, the board meets monthly, with a hiatus during the month of August. Larger boards, such as those of private universities, usually meet quarterly. In such cases, the executive committee will typically meet monthly and undertake business on behalf of the board.

Larger boards typically work through a variety of committees. In a traditional structure, these might include an executive committee, a finance committee, and an academic affairs committee, as well as committees devoted to buildings and properties, campus life, investment, development, board membership, state relations, and special items.

Board committee members also typically are nominated by the board membership committee and approved by the whole board. The membership committee is also responsible for reviewing the effectiveness of the board and its members.

4. <u>The President</u>

In most cases, and in all the best universities, boards entrust significant executive and managerial authority to the president, who, in turn, delegates substantial authority to others, both individually and collectively. The division of governing authority to the board and managing authority to the president has proven itself as one of the most valuable features for building the strength, durability, independence, and value of the U.S. research university.

The president serves as the chief executive officer and the chief academic officer of the university. In most cases, the individual is referred to as the president, but in some public university systems, the president presides over several campuses, each of which is led by a chancellor. In a few private universities, a senior individual serves as chancellor in a non-executive capacity, with a president serving as chief executive officer.

A president's major responsibilities are to lead the effort to define the institution's mission, identify institutional goals, and develop a strategic plan for achieving them. The president also serves as the chief campus spokesperson, setting the tone and establishing the standards of the university on campus, in the community, among alumni, within the state and nation, and with the larger public. The president also insures an appropriate voice for each of a university's many constituencies. Finally, he or she oversees the role of executive officers appointed to serve, so that the president has ultimate responsibility for the instructional, research, and service functions of the university.

The president serves at the pleasure of the board. Contracts vary from place to place, but the president typically receives a three- or five-year contract renewable upon satisfactory execution of his or her responsibilities. Presidential salaries, and those of other individuals in the senior administration of the university, have become highly competitive in recent years. Twenty-seven U.S. university presidents now enjoy compensation of more than $500,000 per year, and a significant number enjoy retention bonuses.

5. Executive Officers and Deans

The president usually selects executive officers, whose appointment is subject to review by the governing board and who, like the president, serve at the pleasure of the board. Executive functions are normally overseen by a cabinet comprised of the following: provost, chief financial officer, vice president for student affairs, vice president for development, vice president for admissions and financial aid, vice president for human resources, vice president for public affairs, vice president for federal and state relations, vice president for facilities, vice president for legal services, vice president for information technology and libraries, and other specially assigned vice presidents. These cabinet members collectively would be referred to as the executive officers. In larger universities, each vice president may have one or several associate or assistant vice presidents, with the role of each broadly defined by the title.

Underneath the framework of campus-wide officers, deans of the schools and colleges within the campus or campuses perform an essential role. A typical research university has a dozen or more colleges, both undergraduate and professional. They might include arts and sciences, the graduate school, art, architecture and planning, veterinary medicine, human ecology, engineering, computer and information sciences, medical school, dental school, and law school.

The deans provide a vital link within the governing and management chain, representing such colleges to the university as a whole. The deans develop strategies for departments grouped within their schools or colleges, allocate resources, and oversee faculty appointments. They also play a major part in determining space and facilities and in fulfilling development activities. Deans typically serve for five-year periods on renewable contracts.

The president, officers, and deans determine, to a significant extent, the character of the American research university. Presidents and deans are typically more independent than their counterparts in other countries. This independence has been a key factor in the growing success of universities in the United States.

6. <u>Faculty</u>

It is frequently said that faculty are the heart of a university, for more than any other single force, they shape the institution's character, expertise, achievements, and stature. They determine which students schools and colleges admit, what will be taught, how programs are organized, what is required for graduation, who will graduate, the standards for faculty appointments, what research is undertaken, and how university outreach is conducted.

One of the most prized aspects of the faculty is their large degree of self-governance. It begins at the departmental level and extends through self-governing schools and colleges. Because faculty members have such great freedom, boards and the community expect them to uphold a high sense of responsibility, which they generally do.

Recruitment and appointment of faculty are rigorous. Typically, after the department chair and dean approves the need for a search, institutions advertise vacant positions in the public press, and those who seek appointment must apply and compete for the job, usually among many applicants. Those hired receive appointments either at the assistant professor, associate professor, or professor level. The assistant professor serves without tenure, usually on a three-year basis;

his or her performance then becomes subject to review. If the individual has served satisfactorily, the appointment is renewed for a further two years, at which time an institution must decide whether to award tenure. This review, in which departmental members as well as members of other departments and external referees usually take part, is searching and demanding. In the end, the individual may be awarded tenure, but the ratio of successful to unsuccessful candidates tends to range from 50 percent down to ten percent in some institutions.

It is noteworthy that evaluation of teaching plays an increasingly important role in tenure review, alongside the evaluation of the individual's research capacity and achievement and his or her contributions to the university's other activities. Post-tenure faculty reviews also are becoming increasingly common, as are limited tenure appointments that require a new review thereafter.

The most outstanding universities provide competitive rewards for faculty, not only in compensation, but also in support for research and teaching.

7. Departments, Centers, and Institutes

The traditional unit of university organization is the department. Departments organize around disciplines, originally to suit the divisions in the curriculum. The boundaries between these disciplines have changed, and an institution will add new departments from time to time. These changes, which are particularly characteristic of science and technology, also emerge in the arts and humanities, where new programs frequently develop within centers or institutes. The introduction of new disciplines and departments, however, does not necessarily obviate the need for older disciplines. The department likewise continues to be the administrative basis of the organization of the university. For example, even when universities have various centers and institutes, faculty appointments reside within departments.

Departments have a strong role in formulating the curriculum, appointing faculty, and developing research. Until some 25 years ago, a professor who was identified as the department head would typically lead each department. These appointments were eagerly sought and were regarded as essentially long-term. More recently, though, a professor whose primary role is as chairman or chairwoman leads each department, usually on shorter appointments. While this shift has some benefits, it also has its liabilities, including making short-term appointees less likely to devote themselves to addressing the long-term concerns of the department, deal with troublesome issues, and act as mentors and advisors to newly appointed faculty members.

As mentioned above, in the last decade, centers and institutes have assumed a bigger role in research and education than in the past. A major research university today may support any number of them, though each such institution generally has from 20 to about 100. This change has mostly occurred because of the increasing importance of interdisciplinary research and the need for focal points for new areas of research. Centers and institutes usually involve faculty members from a range of disciplines and professions cooperating to study a particular topic or broad theme. Faculty members from widely different fields may cooperate in centers or institutes to address problems of an interdisciplinary nature or of common concern. Membership typically comes from within the university itself. Funding may be modest, and come from a variety of internal and external sources.

Some centers and institutes also are inter-institutional, involving participants from several universities and industry and professional groups. In such cases, a board representing the member organizations provides the center's or institute's governance. The bulk of financial support for most centers and institutes comes from external sources. Funding in some cases may be substantial, especially if it involves major federal grants.

A few national centers also exist. They devote themselves to areas of broad scientific and technical interest. Typically, they are supported by a federal agency; located on, or affiliated with, a university campus; and established by an invitation for proposals from competing institutions that may wish to act as hosts. Examples include a national center devoted to the humanities, located on an independent site in North Carolina and supported by the National Endowment for the Humanities; another devoted to atmospheric and astronomical studies, located in Arecibo, Puerto Rico, and supported by the NSF; cancer centers supported by NIH at many medical schools; and supercomputing centers funded by NSF and located at several sites, including the University of Illinois and the University of California, San Diego.

Other research initiatives may be directly operated and supported by a federal agency, such as the NSF program in Antarctica, or in federal research centers on an agency campus, such as NIH's facility in Bethesda, Maryland, and the Centers for Disease Control and Prevention in Atlanta, Georgia.

In all these national centers, the goal is to provide a site with appropriate facilities, equipment, and technical expertise to support advanced research in specialized areas. Teams and individuals typically come to these national centers for limited visits from many institutions and companies. Their interests frequently involve interdisciplinary groups.

National and institutional centers and institutes have been, and continue to be, important sources for new developments in science and technology.

8. Faculty Governance and Roles

Groups of related departments are gathered into colleges. Although faculty appointments reside within departments, as mentioned above, the faculty exercises governance chiefly through these colleges. For example, from time to time and at regular intervals, the colleges convene all members of the faculty to deal with an array of matters related to faculty and institutional business.

Typically, the faculty members of the entire university also are represented in a faculty senate. This senate plays a significant part in campus governance, and the president and provost typically refer many significant educational and research policy items to this body. Within the best universities, the faculty senate plays a major role in developing policy and refining programs.

In some public universities, members of the faculty have also organized themselves into faculty unions affiliated with various public union bodies. It is not clear that this has had beneficial effects on the academic enterprise, though some commentators have suggested that it has financially benefited individual faculty members.

Faculty members in all departments are encouraged to actively contribute to life within the campus as well as beyond it. This work beyond the campus takes many forms, ranging, for example, from continuing professional education and service on local educational boards to advising on crucial matters of public policy. In the sciences and engineering, faculty members typically also carry out significant roles as consultants to industry and as entrepreneurs. The general experience of the universities with regard to faculty consulting and professional practice, whether in music, technology, science, architecture or medicine, is that professional practice and consulting serve not only the faculty, but also students, society and industry. To avoid any real or perceived conflict of interest that might emerge in such activities, universities generally require that faculty members report their professional connections and consultancies to their department chair and dean. As mentioned above, they also are limited in the time they can devote to consulting, usually to no more than one day a week, and also from holding executive positions in companies they have formed. There is not, however, any prohibition from their serving on corporate boards, and indeed this may have some advantage to the university.

Because engagement with private industry can lead to conflicts of interests, universities have developed comprehensive statements concerning intellectual property. These statements govern the role of faculty as well as of postdoctoral fellows and graduate students in their relationships with industry, such as in consulting or funded research. In rare cases, publication may be delayed for a limited period so that patents can be applied for and sponsors of research may first receive the benefit of faculty studies.

In addition to supporting faculty in their roles as entrepreneurs, consultants, and public board members, universities have long made it a practice to provide leaves of absence for faculty members so that they can serve as advisors to government, at both state and federal levels, and as full-time members of government agencies. The detailed arrangements made for such things as pension and other benefits vary from place to place.

9. Students

The primary audience for all faculty and institutional activities is the students. There is also undoubtedly a relationship between the mission, goals, and reputation of the institution and the pool of applicants and the size and character of the student population that it attracts. The system values the quality of students and their geographic, financial, and racial diversity as contributors to student development and an effective educational community. The most outstanding research universities attract both a national and international pool of applicants. Other universities recruit chiefly locally or statewide, but some of these institutions also have strong research programs.

Because of the importance of a high-quality applicant pool, and the great competitiveness among strong universities, such activities as student recruitment, admissions, support, and retention have become highly professionalized. In these activities, universities use market surveys, advertising, studies of student satisfaction, and other tools of modern marketing. In addition, alumni and other friends of the university often assist in recruiting students. Campuses also compete actively with one another in providing programs, state-of-the-art dormitories, athletics, library facilities, and food and medical services, as well as student societies, activities, and associations.

The better universities also attach great importance to a residential arrangement that provides full-time students with housing on or near the campus during all or most of their enrollment. This arrangement provides an opportunity to develop student interest in the community and encourage their participation in community activities, both of which are regarded as highly beneficial to the overall educational experience. In fact, most universities encourage students to participate in community service and to study abroad. These activities are less common among graduate and professional students.

All universities, especially the leading private universities, also strive to increase matriculation, the diversity of their student populations, and the opportunities for students from less-wealthy families by providing them some form of financial aid. At the better universities, up to 70 percent of students may receive some form of financial aid, and many of those enrolled will receive financial aid that covers all their tuition, room, and board. In any case, at these universities no student is denied admission if he or she cannot pay the costs. This policy is called "need-blind admissions."

Public universities typically charge much lower tuition than do private universities. The tuition for a full-time student at a public university typically ranges from $5,000 to $10,000 per year. At the better private universities it ranges from $20,000 to $30,000 per year. These costs do not include room, board, books, travel, and other related expenses.

Among graduate and professional students, where admission is also highly competitive, financial support tends to be the norm. It may include research assistantships, fellowships, or teaching assistantships, together with a waiver of tuition and fees. In other cases, such as professional students seeking an M.D. or M.B.A. degree, relatively little financial aid is available.

Students typically enjoy some form of student governance, including undergraduate and graduate student involvement. Such student governing organizations generally have access to university support and facilities as well as to opportunities to influence decisions that affect them. On this latter point, it is worth reiterating that a number of public institutions allow a student representative to be a bona fide member of the board of trustees.

10. Alumni

Alumni in American research universities provide a major source of counsel, funding, support, loyalty, and expertise for institutions. They are usually organized into alumni associations, not only at the national level, but also at the international level. These associations are in addition to alumni subset and interest groups that form around particular themes, such as study tours, continuing professional education, and other activities that bring alumni of like mind or inclination together.

In many private universities, alumni members also serve in campus governance, not only as appointed members of governing boards, but also by directly electing members to serve on the board.

Supporting networks of alumni activities requires universities to maintain accurate graduate records and affiliations. Usually, a senior university official is given this responsibility. It includes communicating and liaising with alumni as well as developing and engaging their interest in the institution. Such initiatives help to strengthen alumni bonds with the institution and motivate the unique source of support and ideas they can provide to the university.

11. Visibility, Prestige, and Recognition

Visibility, prestige, and recognition are by-products of the university's fulfilling a valuable social role and doing it with distinction. Such results, however, are not ends in themselves, and those universities that have sought to achieve them as primary goals have not been conspicuously successful. A social compact developed over a millennium has defined the role of the research university. Because it recognizes the social importance of the university, society provides universities not only with financial support, both public and private, but also with tax benefits and institutional autonomy, convinced that the advancement of learning confers personal benefits, public good, and societal well being. Universities are ultimately communities of inquiry, discovery, and learning, and must succeed foremost in those activities. More particularly, in the U.S., the leading research universities educate a significant number of holders of first professional degrees, educate the majority of Ph.D.s and holders of advanced professional degrees, perform most of the basic research carried out in the country, and play a major role in technology transfer and public service. To the extent it effectively discharges these four roles, a university acquires visibility and prestige.

Visibility and prestige arise especially from effective university partnerships with local, state, and regional institutions. These institutions include, for example, hospitals, R&D centers, industry, public schools, agricultural and environmental demonstration projects, law clinics, commercial workshops, and economic development organizations.

The university also achieves visibility and prestige for its products. These products include students as well as the results and fruits of research, notable alumni, prizes and awards garnered by faculty (especially Nobel Prizes), and economic and cultural contributions to the larger community. These latter contributions include studies of consumer confidence, economic forecasts, and such cultural activities as athletics, museum displays, and theatrical performances. The quality of such activities contributes to the public perception of the overall quality of the university.

12. Ratings and Rankings

Four different groups typically rank universities.

First, financial agencies rank universities according to their financial soundness. Standard and Poor's and Moody's Investors Service, for example, rank the financial standings of universities, which are reflected in the credit available to universities and thereby affect their borrowing capacity to support new ventures.

Second, the press frequently ranks universities. The most widely quoted of these rankings, but by no means the only one, is that of *U.S. News and World Report*. It ranks universities on the basis of undergraduate interests as well as of graduate and professional interests. Such rankings typically are based on ten or a dozen criteria. The rankings change from year to year, and applicants to universities take them seriously. Though taken less seriously by universities themselves, they have become of growing importance because the public attaches increasing weight to them.

Third, government and independent bodies also rank universities. For example, the National Research Council (NRC) has long supported an evaluation of graduate and professional programs, providing a guide to prospective applicants and sponsors. Accrediting agencies, required by law, also provide a kind of ranking, in that their accreditation is required for universities to award recognized degrees.

Fourth, universities are ranked by facts, for example, by amounts of research funding, gifts, endowments, or library holdings. These rankings appear from time to time in publications from the Lombardi Program on Measuring University Performance at the University of Florida, in the *Chronicle of Higher Education*, and elsewhere.

All these rankings frequently become matters of both pride and contention, and, partly because they promote competition, in broad terms serve a useful role in the development of universities.

13. Relationship of Universities to Local, State, and Federal Governments

The relationship of universities to local, state, and federal governments varies at each level. At the local level, the primary expectation is that the university be an effective and responsible member of the community. This relationship is important because the university both depends upon and contributes to local schools, health, and legal services; provides partnerships in everything from economic growth and commercial development to health services; and requires local approval for campus development and construction.

In no small part because they share a spectrum of common interests, the relationships between universities and their communities over the years have tended to be cooperative. But occasionally differences arise, ranging from concerns over student conduct to questions of tax exemption and competition with local businesses. These differences can be serious when they threaten to impinge on the independence of the institutions.

At the state level, public universities, especially land-grant universities, play a vital role in every aspect of societal concern. For all public universities, the state provides a major source of financial support, but requires, in return, a degree of planning, oversight, and regulation that significantly affects the development of the institution. Private universities, meanwhile, must serve chiefly as partners to society in research and development. Both public and private universities, in fact, are assuming a growing and effective role as magnets for attracting business activities to the state and spurring economic development. Both types of institutions tend to receive some assistance from the state for student financial aid, though this varies widely from state to state.

The relation of institutions to the federal government is more distant. Three areas, though, are typically important. First, the federal government provides a large share of financial support for research activities, indiscriminately to both private and public universities, ranging from the sciences through technology to health sciences. Second, it provides resources and support for student financial aid, including both loans and grants. Third, the federal government affects regulation and oversight for all institutions, both private and public. For example, in restricting stem cell research, requiring non-discrimination in employment, and defining environmental requirements in the handling of materials and designing of buildings, the federal government exercises special influence on the life and work of universities.

Because, in general, university relationships with the local, state, and federal levels are growing in importance, most major universities now assign an individual on a full-time basis to manage relationships at each level. Many universities also have advisory boards of faculty members, trustees, and community members, and most major universities have offices in their state capital and in Washington, D.C. Professional associations in which institutions hold memberships also frequently represent the common interests among universities.

14. University as an Economic Entity

Both public and private universities in the U.S. influence local and national economic systems. Further, they aspire to govern their own economic situations. Thus, both internal and external economic matters arise for university attention.

State universities endeavor to create jobs, spin-off start-up companies, attract corporations to their locales, incubate ideas and patents into viable firms, and provide advice and counsel to management of business entities. Some even provide funding to commercialize their research results. In many instances, a mission of economic development has also been specifically assigned to universities. The charters of institutes of technology, for example, tend to specify an economic development mission. A number of universities, both private and public and including MIT, Stanford, and UC San Diego, among others, have made it their own explicit mission to contribute to regional economic development.

Many universities also use their intellectual property to generate royalties and other income to the university. MIT, Columbia University, Stanford University, Florida State University, UC San Francisco, and the California Institute of Technology are examples of success in such activities. The stated intention of these universities is to produce benefits for the society at large, and through this effort to fund additional research and education activities. On occasion, faculty members also participate in commercialization activities and sometimes even move into small-company management. They may even own a substantial portion of a spin-off company. However, if they become corporate executives, in general they will be required to take a leave of absence from the university. In this manner, in recent decades universities have extracted economic benefits for themselves and their communities from forefront academic research. Policies for these pursuits have been established to avoid perturbing academic freedom or diminishing open campus communication, and to prevent potential conflicts of interest or interference with teaching activities.

In industry, economic growth inherently fosters competitive behavior. For research universities, the goal is to achieve the dual goals of research excellence and contributing to economic growth. Success in attracting support from the private sector as well as through competitive government grants has in fact become a key criterion in the annual rankings of research universities. Accordingly, the competition among universities occurs primarily over recruiting the best faculty and attracting the financial resources to obtain research grants and other forms of support mentioned earlier.

Also encouraging competition is the availability of data on university influence in the numbers of jobs created, gross state or national product, numbers of new companies established, numbers of R&D operations attracted to the region, and numbers of patents granted and licensed.

Universities also understand the positive feedback loop between research quality and another crucial funding source, fundraising. The widely known study by the Bank of Boston, *MIT: The Impact of Innovation,*[4] showed that “MIT related companies” ranked this university 24th among national economies worldwide as judged by revenues. This metric of MIT’s economic contributions has not been lost on other universities with similar aspirations.

15. Mechanisms of Competition

Competition is clearly a crucial part of the system. Its influence has grown as excellence has become a driving force for all levels of academic standing, from students through faculty to the level of deans and beyond. Notably, competition in all disciplines and recognition among peers allows younger and meritorious people to emerge as leaders in academia and beyond. This system has indeed become a meritocracy not of the few but of many high achievers, making

[4] Bank of Boston special report by their economics department (March 1997).

seniority, positioning, ethnicity, national origin, gender, previous standing, and personal relations less relevant.

In earlier decades, universities were considered to be purely communities of scholars, and often avoided industrial, defense, and business involvements. But leaders in the universities now see that such involvements give them the opportunity to operate both as scholars and in the name of the public good and economic development. This move away from the image of isolated communities of scholars with hierarchical pecking orders to a collection of independent operatives each serving multiple constituencies—namely, government agencies, communities, alumni, students, scholars, and industry—is a major feature of the modern U.S. research university system. This situation has evolved principally since World War II, when many of these same universities stepped up to augment industry as part of the U.S. war effort and later the protracted Cold War.

While the change has produced a cornucopia of benefits for the universities, it also puts a premium on their being the best in their laboratories, research centers, technology programs, and academic disciplines. As a result, competition among institutions for these benefits has grown.

Sponsors and funding agencies also take many steps to create and maintain a competitive atmosphere for academic research and scholarship. These steps include mechanisms already mentioned, such as the rules and regulations surrounding government grants and contracts that require competitive responses. Another mechanism that encourages competition is the request for proposal (RFP) process. Government and private funders issue RFP's to stimulate competitive proposals from multiple sources, including academic institutions and their divisions. Funding entities widely consider peer review and RFP's the most effective mechanisms for insuring excellence among research institutions, and, equally important, for guaranteeing an equitable competitive environment for all participants.

The broad offering of programs has become another factor in assuring a level playing field in the competition for resources. The federal government continues to institute numerous research and grant programs to encourage wide participation and competition. Some programs are aimed at groups that, because of history, have more difficulties competing successfully, such as minorities in the physical sciences or women in promotion to faculty, while others focus on institutions that are not at a level to compete successfully.

Often these programs are unique to certain agencies. Examples abound, including such activities as the Defense Advanced Research Projects Agency, the Advanced Technology Program of the National Institute of Standards and Technology, focused centers such as NSF-funded ERC's and STC's, and National Aeronautics and Space Administration (NASA) technology-transfer programs. These activities also include the Small Business Innovation Research program, through which a number of federal agencies provide a highly specialized form of funding for small firms (less than 500 employees) to perform cutting-edge R&D that addresses the nation's most critical scientific and engineering needs. Such important private activities as the Howard Hughes Medical Institute and the MacArthur Foundation have in fact made opening new possibilities for competition a favorite mechanism to spur competition. Such opportunities not only spread the wealth, but also engage new participants in the competitive process.

IV. Funding University Research

Research constitutes one of the greatest contributions the system makes to national productivity and competitiveness. As a result, diverse entities—from the federal government to industry to local agencies—have been highly inclined to seek out ways to invest in and support this research. Even though it remains quite independent in its operation, the system has also been flexible and creative in working with such entities to attract resources that make possible a remarkable array of valuable research. The material below analyzes the main strengths of the funding processes that continue to support the system, how this funding has changed over the past 50 years, and what emerging trends seem poised to effect funding for university research in the years ahead.

1. <u>General Observations</u>

University research is heavily affected not only by the R&D budget of the federal government, but also by that of industry. In fact, in the last 50 years, major changes in the total U.S. budget have molded university approaches and policy. The most significant changes have been the following:

- Changes in total U.S. R&D funding
- Changes in the dominant source of funding for U.S. R&D

- Changes in the performers of U.S. R&D
- Changes in the character of work addressed
- Changes in the diversity of academic R&D sources
- Changes in the influence of funding agencies on academic research
- Changes in the type of research funded

Changes in total U.S. R&D funding: As Figure I-16 shows, considering the whole of U.S. R&D, including the private sector and state and federal governments, funding for academic R&D has increased substantially in real terms during the past two decades. (Note: All figures referenced in section IV appear at the end of Appendix I.) Although the average compound rate of growth was less in the 1990's than in the 1980's—4.1 percent per year versus 5.9 percent—R&D expenditures at universities and colleges grew rapidly in the late 1990's after a period of relatively slow growth in the mid-1990's.

Over time, the sources of funding for academic R&D have shifted away from federal and state government and toward other sources of funding, including internal sources such as tuition, philanthropy, and endowments; industry; and foundations and other nonprofits (Figure I-17). This shift became especially marked during the 1980's, when R&D funding from the federal government and the states fell from 76 percent to 67 percent of total institutional funding.

Changes in the dominant source of funding for U.S. research: As Figure I-1 indicates, since 1980, the dominant funding source for overall U.S. R&D is industry. Figures I-2 and I-3 demonstrate the extent to which, by the 1990's, this trend had become established. Although industry accounted for only a small share of the funding for *academic* R&D in 2000 (seven percent), by that year it comprised 68 percent of the $250 billion *total* U.S. R&D budget. By contrast, in 1953 the total funding of R&D was equally split between the government and the private sector. In the 1960's, government spending comprised the majority of total R&D funding (60 percent).

The industry funding of seven percent of academic R&D is also somewhat misleading since it is dramatically different for certain universities. At MIT, for example, industry provides 20 percent of its quite-large research budget; at Rensselaer Polytechnic Institute, industry has provided as much as 30 percent of the research budget in a particular year; and at Georgia Institute of Technology, the industry investment is 21 percent of the research budget.

Many reasons explain the trend toward industrial support for university research. Certainly, the increasing speed of development strains available industry resources and leads it to curtail investments in fundamental research. Industry also enlists the expertise of university researchers because of scarce human resources and limited expertise in the use of instrumentation. Significantly too, the cost of academic effort is less than that industry can easily achieve.

This trend, though, has led universities to look at industry funding more seriously than ever before. In fact, they have taken on most of the tasks that industry previously performed, especially in research, but also in applied areas. They certainly have done so in the life sciences, but also in information technology (IT) and other engineering areas.

As both a result and consequence of such shifts, former dominant industry laboratories renowned for performing basic research have undergone serious reduction, including at Bell Labs, GE, RCA, and IBM. The expansion of industry-sponsored academic research, meanwhile, has raised a host of questions for universities in such areas as intellectual-property policies, evaluation and promotion of faculty, and conflict of interest and issues related to ethics.

Changes in the performers of U.S. research: The total U.S. R&D budget has also changed because the performers of R&D have changed. In broad terms, the three major performers have always been industry, government, and universities. In the past 20 years, universities have slowly increased their participation from less than ten percent to 16 percent, or $38 billion, in 2000. This is a large increase, especially given the uneven distribution of research spending among research universities. On a related note, as research as become increasingly complex and university participation has increased, facilities, space, and equipment have become major pressure points in university planning.

Changes in the character of work addressed: Basic research has steadily increased from ten percent to 20 percent of total national expenditures since the 1950's (Figure I-7). This change in the character of work addressed not only indicates steady progress in the sciences and engineering, but also how industry, government, and society have come to depend upon basic research as a foundation of their well being and progress.

As Figure I-12 shows, the percentage of federal R&D investments devoted to basic research has also increased almost steadily since the 1950's, though this fact is not often recognized. In the 1990's, that trend continued (Figure I-11).

These latest increases took place in the context of changes in federal emphasis due to the end of the Cold War, such as a shift in emphasis away from the physical sciences and engineering to the biomedical sciences; greater emphasis on egalitarianism, exhibited in the support for second-tier universities to improve themselves and rise in stature without compromising the principle of peer review; and the cost-sharing of expensive research facilities and projects with other nations, such as ITER, the International Space Station, global climate research, deep sea drilling, and CERN.

Changes in the diversity of academic R&D sources: The increasing importance to academic R&D of sources for funding other than the federal government is also often unrecognized. Such sources include institutional funds. Universities generate these funds through tuition; licensing income; endowment income; sports; services to the community, region or nation; and fees earned from managing institutions for third parties. As indicated in Figure I-17, since the 1950's, such self-generated funding has increased from ten percent to 20 percent of total university research funding. This funding now exceeds $5 billion per year (Figure I-16).

Changes in the influence of funding agencies on academic research: As these assessments so far indicate, universities can draw upon literally dozens of R&D funding agencies. Approximately 92 percent of federal support for academic R&D does come from five agencies: NIH, NSF, Department of Energy (DOE), NASA, and Department of Defense (DOD). But the multiplicity of funding sources expands the scope of research and makes it possible for numerous research approaches and viewpoints to be heard and funded. These diverse sources of funding also provide a defense against the vagaries of R&D funding that occur in individual agencies. Such diversity of funding sources is particularly important because funding fluctuations among the various agencies do not occur in lock step, but are highly dependent on issues unique to each agency.

Changes in the type of research funded: The main effect of budget changes during the 1990's was to shift funding allocations among fields. Some fields, especially engineering and the physical sciences, grew relatively slowly, while others, notably the biological and medical sciences, grew rapidly (Figure I-21). The latter two fields in fact accounted for 60 percent of the net real growth in academic R&D during the period. This shift in funding occurred in non-federal as well as federal funding.

The shifts in funding among fields have also affected the balance between basic research and applied research and development in the past few years (Figure I-19), because the fastest growing fields—the biological and medical sciences—are more weighted toward basic research than the fields with more modest rates of growth, namely engineering and the physical sciences.

The shifts in federal funding among fields have also affected graduate education. A recent report of the NRC found that, although federal funding of research assistant positions through R&D grants and contracts is only one factor in determining the number of graduate students and Ph.D.s in a field, where data was available for 1993-99, it indicated that graduate enrollments and Ph.D. production generally declined in the fields with less federal funding for research.[5] In those years, graduate enrollments and the number of Ph.D.s earned decreased in physics, chemistry, mathematics, and most fields of engineering, but rose substantially in the biological sciences, medical sciences, computer science, and astronomy.

The changes in the types of research funded have, in total, affected universities differently, depending on their research emphasis and facilities—for example, engineering schools versus universities with academic medical centers. As a result, affected institutions have raised questions about the wisdom of such substantial shifts in funding allocations among fields. An advocacy group, the Alliance for Science and Technology Research in America, has even formed to lobby for greater federal funding of mathematics, engineering, and the physical sciences. This group is attempting to emulate the success that the Coalition for Health Funding has had on the budget of NIH. In addition, several universities strong in the engineering and physical sciences are now building new capacity in the biological sciences. While it remains to

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[5] National Research Council, *Trends in Federal Support of Research and Graduate Education* (National Academy Press, 2001).

be seen what impact such initiatives will have, for the foreseeable future, the shift toward new research areas seems sure to continue.

2. Federal Laws and Regulations

Throughout the history of U.S. universities, federal government legislation has had a crucial impact on their development. The most salient legislation and its results are specified below.

The Land Grant College Act of 1862: This act promoted education and innovation in science and technology by creating a system of publicly supported research universities, which are now called the Land Grant Colleges. At the time of the act's passage, science and technology were understood primarily as agricultural and agronomic activities and mechanical sciences. Every state has at least one such institution, and, in many cases, these institutions have become the state's flagship university or most renowned research or comprehensive university. Examples of research universities that are land grant schools include University of Illinois-Urbana, Pennsylvania State, Purdue, Texas A&M, University of Wisconsin-Madison, Cornell, and many other well known and prestigious schools. Extensions of the act were promulgated in 1890 and 1994.

Bayh-Dole Act of 1980: This act permitted universities to obtain title to inventions they developed with federal funding, and to use or dispose of the intellectual property at their will. It allows universities and government laboratories to grant exclusive or limited rights to their clients. The result has been to generate an incentive for universities to patent or otherwise protect their discoveries. It has become the accepted practice that the income from intellectual property rights activities are shared between the general fund of a university, the department or center that was responsible for the discovery, and especially the faculty member or researcher who appears as the originator of the idea on the patent or copyright application.

Omnibus Trade and Competitiveness Act of 1998: This comprehensive and detailed act placed special emphasis on public/private cooperation to assure full use of ideas, as well as resources, developed through federal grants and financing. It authorized Training Technology

Transfer Centers and Industrial Extension Services, and permitted royalty payments to non-government employees of federal laboratories, many of whom are employees of universities (e.g., Los Alamos National Laboratory and University of California [UC]).

Other Legislation: Many other acts of the federal government, although not primarily aimed at institutes of higher education, had an impact on them. In particular, *The Cooperative Research Act of 1984* allows companies in the same field to pool resources for research and engage in joint pre-competitive research, free of previously enforced anti-trust constraints. Often, universities perform this joint research, funded by industry sector consortia, such as the Semiconductor Research Corporation.

As such acts make clear, the government can often motivate and accelerate the process of discovery in universities, or be a barrier to such activities. The Bayh-Dole Act offers an informative example. Recent studies have concluded that in the two decades since its enactment, the number of patents owned by universities has increased seven-fold, and the number of academic institutions that have a patent portfolio has increased almost three-fold (Figure I-23).

Similarly, the Cooperative Research Act has led to increases in the number of papers authored jointly by researchers in industry and universities. For instance, in 1999, 82 percent of the cross-sectoral scientific and technical papers produced by industry were in collaboration with academic partners. On a related point, the average number of citations in U.S. patents to academic scientific and technical papers has increased five-fold in the last decade. While the reasons for this development are many and complex, additional collaboration between academia and industry certainly contributed to these increases and with them to a fundamental change in the way research in the U.S. is performed.

V. Case Studies

We have selected four institutions—the Massachusetts Institute of Technology, Stanford University, University of Texas at Austin, and University of California, San Diego—to demonstrate the variety and diversity of U.S. research universities, their varied growth patterns and history, and the impact they can have on their nation and regions. We also, where possible, address the influence of each institution's IT, electronics, biotechnology, and business areas. The observations were obtained from literature and discussions with individuals who are associated with or have a special relationship with the selected universities.

1. Massachusetts Institute of Technology (MIT)

VITAL STATISTICS

Location

Boston-Cambridge, Massachusetts, is known as a center for knowledge-based activity. It includes outstanding academic institutions: Harvard, Boston University, Tufts, Wellesley, and Radcliff. Thanks to its focus on engineering, technology, and science, MIT is also a principal player in this firmament. The well-known Route 128 complex of industries and the Cambridge-Boston biotechnology corridor typify the surrounding economy. These industries cover a range of products, services, and inventions.

Boston and Cambridge are a Mecca of cultural activities, museums, and music, and are close to winter-sport locations. Summer recreation sites and beaches surround Cape Cod, a nearby destination. There are fine restaurants, many of which are long established and offer outstanding seafood. Public transportation is good, and Boston is a convenient jumping-off point for travel to Europe, Canada, and the eastern U.S. There is no big-city atmosphere, however, that might hinder the pleasant experience the area provides.

Such factors have enabled Boston-Cambridge to attract an ethnically diverse cohort of students, university faculty, and entrepreneurs, among others.

On the negative side, a road construction project, locally known as the Big Dig, has spoiled Boston downtown for far too long and still seems years from completion. Other construction at Logan Airport has resulted in similar long-standing travel inconveniences.

Basic Facts

- **Faculty**: The 960 faculty of MIT include 232 National Academy members, ranking MIT third in the U.S. in this metric. MIT has been particularly successful in finding high-quality young faculty who rise through the ranks to become internationally famous.

- **Students**: Enrollment at MIT exceeds 10,000, 60 percent of whom are at the graduate level. The median SAT score at entry is 1485 (out of 1600), and enrolled students include 185 National Merit Scholars.

- **Graduate Degrees**: MIT graduates about 500 doctoral recipients each year.

- **Research funding**: Competitive research support from the federal government totaled $307 million in 2000. The same year, MIT's total research was $426 million. These figures rank MIT 7th in federal research funds and 11th overall. In this regard, it must be noted that MIT does not have a medical school. Funding for such schools inflates the research dollars of those universities that have them. MIT's Whitehead Institute for Biomedical Research does obtain substantial funding for its research, but since MIT does not a medical school, its research figures would inevitably be lower than otherwise might be expected.

- **Endowment**: MIT's endowment in 2001 was $5.6 billion, placing it 5th among all U.S. universities.

DISCUSSION

MIT is widely considered to be the preeminent institute of technology in the world. It is recognized as a valuable national asset for the U.S. and beyond, its graduates are leaders in their fields, and its inventions and intellectual property have been the basis for new companies, new products and services, and new knowledge in many fields of endeavor. MIT's unique position in the world ultimately may be attributed to four main factors: leaders competing to recruit the best faculty wherever in the world they can be found; the high quality of its students; an entrepreneurial tradition that dates to its founding in 1861; and a commitment to public service—for example, four science advisors to U.S. presidents came from MIT.

Perhaps the most remarkable feature of MIT has been its ability to retain its distinguished stature for more than 50 years. MIT was founded in 1863 as "Boston Tech," located in downtown Boston. Shortly afterward, it moved across the river to Cambridge, and has been thriving ever since. Many people believe that the succession of outstanding MIT presidents—from the first, William Barton Rogers, to today's, Charles Vest—is largely responsible for its remarkable evolution and sustained excellence throughout this history.

MIT's leadership in research and education also stems to a major extent from an open policy that attracts talent worldwide. Foreign students and faculty, including visiting faculty, have brought talent and expertise into MIT's orbit, benefiting all distant comers as well as locals. Significantly, MIT has also led the system in bringing women into its faculty and student populations.

A major factor in MIT's preeminence has been its role in originating technological ideas supported by superb science and mathematics. Such concepts as feedback, stability, optimization, decision-making, modeling, programmable computers, and supersonic aircraft, for example, originated or developed into mainstream engineering concepts at MIT.

MIT's rise in the physical sciences and mathematics began more recently, around 1955. Since then, its physics, chemistry, and planetary science departments have risen to the top ranks in the country. The same can be said for its business school and its economics department. The business school, the Sloan School of Management, has led the way in applying modern business and analytical tools to real-world situations and also in relating technological innovation to wealth and job creation. The economics department boasts several Nobel Prize winners, including one Nobel laureate honored for quantitatively relating the introduction of new technologies to productivity increases.

The institute's engineering prowess has recently been bolstered by a curriculum in humanities and social sciences. Further, although engineering and the physical sciences have been the bedrock disciplines at MIT, the life sciences have emerged as close partners. The addition of biology to the curriculum and the establishment of the Whitehead Institute for Biomedical Research have put MIT at the cutting-edge of this now leading discipline and its application. Biology at MIT is now ranked as the best in the country, and has spun-off many biotechnology companies and led to the location of both large and small biotechnology companies close to MIT, making Boston a national focal point of this field.

A watershed in MIT's development and emergence occurred during World War II: MIT was the site of the famous Radiation Laboratory that led to the development of radar, sonar, and precision controls and to the defeat of the Axis Powers. MIT's wartime role also led to the emergence of modern engineering and revolutions in electromagnetic applications and communication technologies. The same thrusts resulted in progress in so-called man-machine interactions and eventually the world-renowned Media Lab. In keeping with such preeminence, MIT is now a leader in homeland security and nanotechnology.

MIT has also moved forward in entrepreneurship and commercialization of research outcomes. A major objective of MIT's interest in these matters has been the spinning out of start-up firms based on MIT inventions. The extent of this activity was documented in the Bank of Boston study noted earlier, *MIT: The Impact of Innovation*. It points to 4,000 MIT-related companies employing 1.1 million people and having worldwide revenues of $232 billion, roughly equivalent to the GDP of South Africa and of Thailand.

MIT has also sought to build close relationships with industry. Besides encouraging joint research, the institute encourages commercialization and technology transfer. The Industrial Liaison Program (ILP) focuses such industrial interests. Membership in the ILP is based on a yearly subscription fee. In return, corporations have preferred access to faculty and students, as well as licenses. ILP holds a yearly review of MIT research for its members and circulates its publications to its corporate contacts.

Besides industrial firms and commercial companies, alumni and other sources support MIT. This broad base of support has enabled its current campaign for building its endowment to raise more than $1.5 billion so far.

In a report issued in 2003[6] it was found that the eight research universities within a nine-mile radius of Boston, including MIT and Harvard, were responsible in one year alone (2000) for:

- $7.4 billion increase in the regional economy
- 37,000 jobs in addition to the 49,000 positions at the universities
- a talent pool of 32,000 graduates each year
- innovative research that resulted in 264 patents, 280 commercial licenses of technology, and 41 start-up companies

- continuing education for 25,000 non-degree students

2. Stanford University

Today, Stanford ranks in the highest tier of research universities by any measure, including the amount of federal and other funding for research and development, number of research doctorates degrees awarded annually, output and impact of research articles, and quality and productivity of its faculty. After World War II, though, Stanford was not considered a leading research university. It rise in stature has come in part from its own strenuous effort to improve itself through a variety of strategies, the key ones of which are described below. These strategies capitalized on post-war developments in federal R&D policy; the takeoff in the electronics, aerospace, and computer industries; strong state economic growth; and other factors.

VITAL STATISTICS

Location

Stanford is just north of the Santa Clara Valley, now better known as Silicon Valley, about 35 miles south of San Francisco, in northern California. The campus is located on part of the more than 8,000 acres donated by Leland and Jane Stanford to establish the university, which opened in 1891.

The campus is beautiful, and buffered in part from the enormous growth in area population by undeveloped areas of its original land grant. The climate is pleasant, and the life style relaxed compared with eastern colleges and universities. This features no doubt help in recruiting and retaining top faculty and attracting students. In the recent past, especially in the 1990's, the area's population has expanded greatly, which has resulted in terrible traffic conditions and very high housing costs.

The campus is across the street from the city of Palo Alto, a city with approximately 61,000 residents, and next to several developments on Stanford land, including the Stanford Research Park and the Stanford Shopping Center.

Stanford Research Park was created in 1951 to provide income for the university, which it does. It also, though, fostered close interaction between the university and emerging high-tech

[6] *Engines of Economic Growth: The Economic Impact of Boston's Eight Research Universities on the Metropolitan Boston Area* (Appleseed, 2003). This report was prepared for the Greater Boston Chamber of Commerce by

industries, beginning with electronics. Current tenants include more than 140 companies in electronics, software, biotechnology, and other high-tech fields, which employ about 25,000 and occupy ten million square feet in more than 160 buildings.

Basic Facts

Faculty: Stanford has 1,701 tenure-line faculty, 55 percent of whom have tenure and 313 of whom hold endowed chairs. These include the following:

- 17 Nobel laureates (three affiliated with the Hoover Institute) (over its history, Stanford has had 25, beginning with Felix Bloch in physics in 1952)
- Four Pulitzer Prize winners
- 23 MacArthur Fellows
- 21 recipients of the National Medal of Science (including two affiliated with the Hoover Institute)
- Three National Medal of Technology recipients
- 124 members of the National Academy of Sciences (NAS)
- 83 members of the National Academy of Engineering (NAE)

Students: In 2001, Stanford enrolled 6,637 undergraduate students and 7,536 graduate students (in 1950, there were 4,805 and 2,907, respectively). In 2000, Stanford had 4,604 full-time graduate students in science and engineering, the third most in the country. More than half of these graduate students were in engineering fields. Among all fields, electrical engineering had the most graduate students, 742. This has been a key department since the mid-1940's, as explored later, and the single most important driving force in Silicon Valley's emergence as the world center of electronic components and instrumentation.

In 2000, Stanford had 1,196 postdoctoral appointees, second only to Harvard. Most were in the biological sciences and health fields (480 and 495, respectively).

Graduate Degrees: Sixty-three departments and programs in seven schools award graduate degrees. In 2001, Stanford awarded 547 earned research doctorates. Of these, 440 were

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Appleseed, a New York economic research firm.

science and engineering (S&E) doctorates, the fourth most given by any university (the others: Berkeley, 538; Illinois, 476; and MIT, 443). The largest number of S&E doctorate awards was in biology (70), followed by the social sciences (67) and electrical engineering (59).

Schools, Centers and Institutes: The seven schools of Stanford are business, earth sciences, education, engineering, humanities and sciences, law, and medicine. The business school is highly regarded and, together with the other schools, especially engineering, has been instrumental in supporting regional development and industry. Engineering also provides more than the standard offerings in that field. From its early days, it has incorporated computer science and system design and concepts in a broad way.

Stanford also has several important research centers. The Hoover Institute was established in 1919, originally to collect documents on the causes of World War I. It is now a public policy research center. The Stanford Linear Accelerator Center (SLAC), a federally funded R&D center established in 1962, operates the world's longest and most powerful linear accelerator, the B-Factory Project, and the Stanford Positron Electron Accelerating Ring. The SLAC staff totals about 1,350 and includes 250 Ph.D. scientists, and other researchers from universities and laboratories around the world use the facilities.

Finances: In 2001-2002, Stanford's consolidated budget for operations was $1.9 billion, which included all annual operating and restricted budgets that support teaching, scholarship, and research, including the budgets of all schools and administrative areas and SLAC. This figure does not include the capital budget or the budget for hospital and clinical services. The capital budget for 2001-2002 was $316 million.

Stanford had the 6th largest endowment among universities as of June 30, 2002 ($7.6 billion), some of which it uses for current expenses, and it ranked second in fundraising ($499 million).

Research Funding: In 2000-2001, the budget for sponsored research support was $660 million, including the SLAC. The federal government provided approximately 90 percent of the support. Stanford's largest federal funder of R&D in 2000 was the Department of Health and Human Services (HHS), which comprised virtually all of Stanford's NIH funding. The percentages of the $355 million by agency totaled 55 percent, HSS; 14 percent, NASA; 13 percent, NSF; 11 percent, DOD; and six percent, DOE.

Research Advances: Researchers at Stanford have made many advances, some of which have had direct economic impacts. A short list would include the Klystron Tube (in 1937), nuclear magnetic resonance, synthesized DNA, recombinant DNA, and high-energy physics at SLAC, including six Nobel Prizes for discoveries in high-energy particle physics.

Licensing Revenues: In 2000, Stanford reported to the Association of University Technology Managers that it had earned $34.6 million from 378 licenses. That year, Stanford ranked 5th in licensing revenue. Stanford also reported that it had been issued 98 patents and formed eight start-up companies. On its website, Stanford identifies some of the technologies, patented and licensed, earning the most royalties for the institution. The most profitable in the 1975-1998 period earned the institution more than $400 million.

Start-ups: Stanford tracks companies started by its professors, students, and researchers. On its "Wellspring of Innovation" website, Stanford has identified about 1,200 companies and nearly 1,700 founders with Stanford affiliations. For example, Professor Irving Weissman and postdoctoral student Michael McCune invented a mouse with human immune system cells (the SCID-hu mouse), and formed a company (SyStemix, since acquired by Sandoz) to raise millions of dollars to finance a search for human stem cells. Stanford reports that Stanford start-ups account for 37 of the Silicon Valley's 150 largest companies, 42 percent ($106 billion) of the revenues of the 150, and 36 percent of the market capitalization of the 150. Some of the firms founded or co-founded by Stanford affiliates include Hewlett-Packard, Cisco, SUN Microsystems (SUN stands for Stanford University Network), Agilent, Silicon Graphics, Varian, Intuit, Nvidia, Adobe, Symantec, Yahoo, eBay, Affymetrix, and Incyte Genomics. This list does not include important companies since acquired by other companies, such as MIPS Technologies, Inc., which developed the chip used by Silicon Graphics.

Rankings: In recent decades, Stanford has done well in periodic assessments of graduate programs in the United States, ranking 5th in the 1966 Cartter assessment, 3rd in the Roose-

Anderson study of 1970, and 6th in the 1995 NRC assessment of research doctoral programs. In the 1995 study, Stanford was ranked among the top ten universities in 28 of 35 fields it offers, the top five in 16, and first or tied for first in six.

The Lombardi Program ranks universities on nine factors: total research expenditures, federal research expenditures, endowment size, annual voluntary giving, number of members of the national academies (NAS, NAE, and Institute of Medicine), prestigious faculty awards, number of doctorates granted, number of postdoctoral appointees, and median SAT scores. In the Lombardi Program assessment using 2001 data, Stanford was one of three institutions that ranked in the top 25 on all nine measures (the other two were Harvard and MIT). Finally, *U.S. News and World Report* ranks Stanford as number four among doctoral-granting institutions.

DISCUSSION

Stanford is an example of an institution that moved up substantially in university rankings in the years after World War II, primarily due to its leadership in developing the electronics industry, especially the semiconductor industry. It thus became a model for how to contribute to a region's economic competitiveness, increase institutional research funding, and through it all improve academic standing.

During its first 50 years, Stanford was overshadowed by the universities of the U.S. East and Midwest and by its close neighbor, the UC-Berkeley. Although an original member, in 1900, of the Association of American Universities, which includes most of the finest universities in the country, Stanford went through difficult times during the Great Depression and was unable to grow or maintain its position in a number of fields such as physics. As a consequence, it was not a major contractor to the government in World War II and certainly not in the top 25 in terms of dollars received. In fact, one of its leading faculty, Frederick E. Terman, and his best colleagues moved to Harvard during the war. There, Terman headed the Harvard Radio Research Laboratory, which was instrumental in developing radar countermeasures.

Upon his return to Stanford to resume his position as dean of engineering, Terman was determined to move Stanford from the bottom ranks to the top tier of research universities by increasing research funding and building peaks of excellence in key areas of interest to funding sources, beginning with electronics and semiconductors. He seized on the increasing support of the federal government for research in universities and, fully supported by Stanford's president, became the prime mover in transforming Stanford from a primarily undergraduate college not particularly recognized outside California or the U.S. west coast to what is now widely recognized as one of the greatest universities in the world.

Terman, importantly, had a broad view of what a faculty member should be: a teacher, a researcher, and someone who can intensely interact with communities outside academia, especially industry. He was not only supportive of his brightest students, such as William Hewlett, David Packard, and the Varian brothers, but also encouraged them to start their own companies and lean on Stanford for needed technical and business support. Later on, Professors Linvill and Meindl followed in Terman's footsteps and founded and participated in high-technology spin-offs and development.

Stanford and again Terman were instrumental in establishing Stanford Industrial Park, which attracted industry and Stanford's students to form laboratories and companies near the university. Stanford used the profits from the real-estate transactions involved as a "fighting fund" to hire top faculty and outfit its laboratories.

This mix of entrepreneurship, teaching, and research became a hallmark of Stanford and permeated its departments. It also helped establish the economy and culture of Silicon Valley.

Stanford, in sum, recognized after World War II the new research frontiers in electronics, materials, and aeronautics, among others; became aggressive in securing federal funds; established a policy of working closely with industry in developing new technologies; and created an entrepreneurial culture and tradition of start-ups. Significantly, this tradition of entrepreneurship and start-ups has not only been emulated by other universities and regions, but also has continued at Stanford. For example, in 1984, John Hennessy, an associate professor of electrical engineering, left Stanford on sabbatical to found a company to commercialize applications of research he had performed on Reduced Instruction Set Computer (RISC) architectures. The company, which became MIPS Technologies, was later acquired, as noted above, by Silicon Graphics (itself started by a former Stanford assistant professor), in part to provide the chips for its computers. Meanwhile, Hennessy returned to Stanford and rose through the ranks, from professor to dean to provost and, in 2000, to president.

A Postscript to the MIT and Stanford Case Studies

The analogy of MIT and Route 128 has not escaped the critical eyes of sociologists.[7] In particular, they have addressed and studied the reason for the continuous growth of Silicon Valley and the relative decline of Route 128. Saxenian identifies the culture and history of the two regions as the deciding difference: Boston is patriarchic, class-conscious, and reserved; Palo Alto is open, sharing, and "laid-back." These differences, she infers, also apply to the two universities instrumental in the creation of both industrial regions: Stanford actively helpful; MIT more passively participative. The truth, however, may be more complex. The Route 128 high-technology corridor declined in part because of the decline in DOD funding for its kind of specialties. True, Stanford and Silicon Valley beat out MIT and Boston in computer and network technology. But the biotechnology industry grew in Boston as strongly as in northern California.

3. University of Texas at Austin (UT-Austin)

VITAL STATISTICS

Location

With rolling hills, a chain of lakes 150 miles long, 300 days of sunshine a year, and an arts and entertainment scene so energetic it is hailed as the "Live Music Capital of the World," Austin has been named as one of the nation's best places to live by *Money* magazine.

Austin is the seat of Texas government, and rich in educational offerings, having seven area universities. It offers a strong, diversified economy. Its technology sector is powerful, with firm roots in electronics and semiconductors, computers, and peripherals and software. It is home to Sematech, a consortium of companies in the semiconductor industry to conduct joint R&D, which has attracted other institutions to the region. Film and music make the city buzz with creativity. Other industries, such as biosciences and multimedia, are poised for expansion. With a combination of real estate, infrastructure, and a diverse and skilled labor force, the greater Austin region has experienced extraordinary growth. A temperate climate, big-time sports in a small-

[7] Annalee Saxenian: *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (Harvard University Press, 1994).

town atmosphere, and unique natural and cultural features further explain why Austin's population doubled every 20 years throughout the past century.

Such features together explain why the UT-Austin, the largest single-campus university in the nation, has an advantage in recruiting outstanding scientists and engineers to its faculty.

Basic Facts

- **Faculty**: The faculty is composed of Nobel laureates, Pulitzer Prize winners, MacArthur fellows, and hundreds of members of prestigious academic and scientific organizations. The university, for example, ranks 4^{th} nationally in the number of faculty who are members of the National Academy of Engineering (NAE).

- **Students and Alumni**: Fall 2002 record student enrollment totaled 52,261. UT-Austin has more than 302,000 alumni across the nation, 19,000 international alumni, and the 4^{th}-highest enrollment of international students in the country (4,444). Its student body is 2^{nd} only to Harvard University in the number of National Merit Scholars.

- **Degrees**: The university annually awards more than 11,000 degrees and offers more than 100 undergraduate degree programs and 170 graduate degrees. In total number of doctor's degrees conferred, the university ranks 2^{nd} in the nation. In science and engineering doctor's degrees conferred, the university is 5^{th} in the nation and 1^{st} in Texas.

- **Doctoral Programs**: Seven doctoral programs at UT-Austin rank in the top ten in the nation, and 22 others rank in the top 25, according to a comprehensive study of the quality of graduate schools conducted by the NRC in 1995. Among Texas schools, the university is ranked 1^{st} in 30 of the 37 fields in which it was evaluated. The report, *Research-Doctorate Programs in the United States—Continuity and Change*, covered more than 3,600 research-doctorate programs in 41 fields of study. UT-Austin programs that ranked in the top ten are civil engineering (4^{th}), computer sciences (7^{th}), aerospace engineering (8th), classics (8th), astrophysics/astronomy (10th), chemical engineering (10th), and ecology, evolution and behavior (10th).

- **Research Funding**: Scholars at UT-Austin annually receive more than $300 million in federal and private research grants and contracts. Through its Austin Technology Incubator, which is internationally recognized for technology commercialization, the university has spun off 65 companies that have generated, cumulatively, more than $1.2 billion in revenue. The university's research facilities, including the J.J. Pickle Research Campus, the Marine Science Institute, and McDonald Observatory, house more than 90 research units. The university has been awarded more than 400 patents since its inception.

- **Economic Development**: UT-Austin builds economic strength for all of Texas. With about 21,000 employees, it is Austin's largest employer and one of the largest in the state. It generates an annual level of Texas business activity totaling $5.7 billion, as well as more than 80,000 jobs and $2.1 billion in personal income. Its students provide an annual economic boost of $544 million to the local economy. Student spending leads local businesses and their employees to spend another $1 billion in the Austin area.

DISCUSSION

Founded in 1883 as a small campus on 40 acres near the state capitol, UT-Austin is the oldest and largest component of the University of Texas System. Today, it is the state's greatest resource of intellectual capital. It serves Texas and the nation as one of the most highly rated public research universities in the United States. Indeed, a vital distinction of this university is its importance to the economy of the State of Texas, especially its role over the past 25 years. During this time, the financial base of the state moved from oil and gas production to high-technology sectors such as computers, semiconductors, and biotechnology.

The university has long been a pioneer and leader in establishing innovative educational programs in technology, research partnerships with the private sector, and productive basic and applied research to support knowledge-based industries in Texas—vital factors in determining the economic future of Texas. It has served as a national leader in generating scientific and technological breakthroughs, and in preparing professional workers to meet the demand for skilled scientists and engineers. Through its business school and specially designed centers and institutes, it helps Texas entrepreneurs by providing financial and marketing advice, developing business plans, helping to train workers, developing and testing equipment, and other services.

Every major chip manufacturer has headquartered its chip design centers in Austin. The attractions include the proximity of UT-Austin's engineering and science research faculties as well as its highly trained and disciplined graduates, who make outstanding professional employees. Michael Dell, for example, founded Dell Computer in Austin as a student on the UT-Austin campus. At least 75 percent of the semiconductor industry has a home in Texas, one reason that nanotechnology research at the university has thrived. With an environmental faculty ranked among the nation's top five, the university also conducts helpful research and educates productive graduates seeking to restore and improve the natural world.

Over the years, the state government has supported the growth in size and quality of UT-Austin's research and training in the sciences and engineering. An innovative example was the establishment, some 25 years ago, of a state science foundation modeled after the NSF. It distributed $70 million annually in competitive grants for applied research by university faculty. The peer reviewers were experts recruited from outside the state to avoid bias, conflict of interest, and political pressure. In addition, wealthy donors provided endowed chairs (over 100 for UT-Austin alone) to recruit outstanding faculty. Partly as a result, Texas universities and colleges rank 3rd nationally, just behind California and New York, in total R&D expenditures, which includes federal, state, industry, and university sources.

All of these initiatives combined explain the rise in stature of the engineering school, in less than a generation, from its modest standing to its current ranking within the top ten in the country. The College of Natural Sciences has improved significantly as well.

As with UC-San Diego, which is discussed below, UT-Austin's academic achievements and economic contributions grew from the following: the search for and retention of excellent faculty; political and industrial leaders who understood the connection between a strong research university and economic growth and provided the necessary resources; university administrators who developed these resources in support of the talented faculty they assembled; and active industry-university connections.

4. University of California, San Diego (UCSD)

VITAL STATISTICS

Location

San Diego has been called one of the most attractive cities in the United States in which to live. It is a seaside community with an agreeable climate. Its economy is broadly based in biotechnology/pharmaceuticals, telecommunications, aerospace, instruments and medical devices, information technology, tourism, and university education and research. It is ethnically diverse, with a large Hispanic population. It is culturally rich, with a famous symphony orchestra, opera, and museums.

Basic Facts:

- **Faculty**: UCSD has 732 tenured and tenure-track faculty members, of whom 99 are members of the national academies. This ranks UCSD 2nd among public universities, and 6th among all research universities, in this metric.

- **Students**: Enrollment totals 20,000, and continues to grow rapidly because of the attractiveness of the site and the quality of the faculty.

- **Research Funding**: Federal research support totals $326 million, mostly competitively awarded and about 50 percent of which is awarded to the life sciences. Considering the impact of medical schools, as noted in the discussion of MIT, it must be noted that UCSD has a medical school with major research programs in the biomedical sciences. In federal funding, UCSD ranks 3rd among public universities and 5th among all universities. On a related note, UCSD ranks 4th in the world in terms of the citation impact of its research publications, according to the Institute for Scientific Information, and 10th in the quality of its faculty and graduate students, according to the NRC.

- **Economic Impact**: The founders of UCSD wisely chose to emphasize science and technology and to include a medical school, while in recent years UCSD has been wise to build its programs in biomedical science and IT. As a result, San Diego and the UCSD campus have together become a hub for IT, electronics, supercomputers, and biotechnology-related R&D and industry. For example, a UCSD faculty member who was also a graduate of MIT started Qualcomm, a world leader in the mobile telephone revolution.

DISCUSSION

For UCSD to achieve such eminence in little more than four decades since being founded is remarkable. The underlying reasons for this achievement provides some answers to the question, what makes a great research university?

San Diego was ready for a state-sponsored university by the mid-1950's. However, the leadership provided by the scientists at the world-famous Scripps Institution of Oceanography, established in San Diego in 1903 from private donations, set the course of its evolution. Drawing upon their experience as eminent scientists, they proposed an early institutional emphasis on science and technology, and most importantly, the recruitment of accomplished, proven scientists. These visionaries then raided the great research universities in the eastern U.S. for their superstar faculty, offering tempting financial support, a high quality of life, and participation in the adventure of launching a new university.

The early support of San Diego's political and industrial leaders was another crucial ingredient for the rapid ascension of UCSD to a national leadership position. These influential citizens, perhaps because of the wartime success of American science, recognized the ultimate commercial value of excellent scientific research. Indeed, they were among the first prominent Americans to recognize the importance of an emerging knowledge-based economy. They arranged for land to be provided to the new university by the city, for private donations to initiate construction, and for state public money to begin flowing to the needs of UCSD.

UCSD, however, did not escape the turbulent days of U.S. student unrest of the 1960's and 1970's. In those days, links between faculty scientists and industrial counterparts were not strong, to say the least. But several factors combined to foster an entrepreneurial spirit among many faculty members, including the pharmaceutical industry's growing support of academic research, provided without being overly intrusive; the Bayh-Dole legislation that was the catalyst for technology transfer; and the policies of a UCSD chancellor, Richard Atkinson, who had been both a renowned academic scholar and a successful commercial innovator.

The role of UCSD in contributing to the relatively successful economy of the San Diego region is generally recognized. The graduates have given high-technology companies a pool of especially skilled talent. Many of the faculty and graduates have launched successful, internationally visible companies in the biotechnology, telecommunications, IT, medical diagnostic, and materials sectors. A recent survey shows that 160 successful companies trace their roots back to UCSD. Further, UCSD administrators have established multiple links for interactions among university scientists and business managers.

The results prove the truism that success breeds success. Along with the rest of the country, California is experiencing a recession, and as a result the governor has reduced state research funds for universities. Yet, the state has agreed to fund some 700 new faculty positions at UCSD over the next few years in anticipation of a flood of students to this highly regarded university. In addition, the governor has not rescinded $100 million of new funds to launch a major research initiative in telecommunications/information technology that will be based in UCSD on the condition that the private sector match the investment. Even in the difficult economy, private contributions responded by oversubscribing by a factor of two.

A business/management school was established at UCSD three years ago. The new dean reported that he intends to recruit students who have undergraduate degrees in science or technology and to emphasize "technology entrepreneurship, bringing new concepts to the market place, and knowledge for competitive advantage."

UCSD is, to state it succinctly, a role model of a successful research university. Similar to UT-Austin, its achievements have grown from the identification, recruitment, and retention only of outstanding faculty; federal funds that flow competitively to these scholars; political and industrial visionaries who recognize the value of building a top university in their community and who maintain active industry-university connections; and academic leaders who encourage and find support for their talented faculty.

5. Lessons Learned from Case Studies

The four case studies illustrate much about the dynamics of the U.S. research universities, including the following:

- The system is not static: universities can rise in prestige and effectiveness; by inference they can also decrease in prestige.
- The system does not differentiate between private and public institutions; what matters most is the level of attainment and the competitiveness of the institution.
- The growth of a particular university is not dependent on where it is located. The case study institutions, for example, are the U.S. East, West, and Southwest.
- A relatively short time is needed for major advances: Stanford rose to eminence in 40 years, UCSD Diego in 25 years, while UT-Austin only surfaced and grew to its present eminence in 20 years or less.
- The driving forces for the rise to excellence are many. MIT's major growth resulted from World War II and the Cold War. UCSD grew into preeminence through achievements in biosciences and communication. Stanford has made its most distinguished contributions in furthering the understanding of computers, semiconductors, and related operations. UT- Austin, finally, established its excellence by becoming the key element in the success that the State of Texas has had in diversifying industrially and reducing its dependence on natural resources.
- A common trait of the four universities is that they know how to enlist support from multiple sources, including federal and state governments, the private sector, and such internally developed resources as endowments, real-estate dealings, and other institutionally related businesses.
- While there is no agreed-upon metric for judging a university's status, little disagreement exists over which are the top universities and why they attained that stature.

VI. Observations and Outlook

The underlying motivator of U.S. research universities can be summarized simply: *The goal is excellence, and the tool is competition.* While great differences separate the various leading institutions, this principal motivator is common to them all. Several features of the system, however, are worth summarizing.

1. <u>Social Context</u>

To be competitive, discharge its roles, and fulfill its potential, the university needs an acceptable social context and an environment that furthers these prime objectives. Its success depends on at least the following factors:

- Public policies and attitudes that encourage discovery and invention, with the conviction that they serve the public interest.
- A long tradition of institutional autonomy for universities, and a strong commitment to openness and intellectual freedom for their members, which together create an aura of impartiality.
- Demonstrable results that universities are making major contributions to economic strength and technological success.
- The availability of substantial external funding to support campus R&D. While most of this support comes from federal funds, essential funding also comes from industry, foundations, state governments, and the institutions themselves.
- Broadly based policies of competitive research funding, in which peer review is the evaluation mechanism for proposals submitted by individual faculty members, both junior and senior.
- A business climate that favors investment in new technology and responds to new inventions within the free-market system.

- Government regulations and fiscal policies sympathetic to unrestricted, open, fundamental research as well as to entrepreneurial activity and technological investment.

These distinctive aspects of the modern research university environment, and those described in section II, do not guarantee beneficial technological and economic returns. Nor may they be the best way to organize a sprawling and diverse university system. The U.S. system, after all, is not well articulated or tightly organized. It is instead a loose confederation of largely independent, highly motivated, well-managed, broadly based institutions characterized by high standards in competitive recruiting, a strong research and funding environment, and a minimum of governmental regulation. But the system enjoys a supportive, free-market environment in which both public and private funding support its various educational and research programs. This culture, at least within the United States, has produced remarkably beneficial results.

2. <u>Institutional Diversity</u>

While different rules, laws and regulations govern the public and private universities that constitute the system, the same input and output parameters measure these institutions. Their standing also is independent of whether they are private or public. For several decades, the six top U.S. universities have been comprised of three public and three private institutions, with the particular universities varying from period to period.

Among the 200 or so U.S. research universities, the top-ranked institutions[8] achieve their high position on the basis on such factors as the ability to compete for research funds, the quality of faculty, the measures of advanced training, and the quality of students. Using a metric based on endowment, annual gift income, tuition income, and state appropriation, a measure of endowment wealth is derived that equalizes the sources of wealth of these institutions. The analysis in the Lombardi Program report shows that the best American research universities—public and private normalized in a common list, and regardless of physical size—are also, in this sense, the wealthiest. In other words, public universities whose states provide more money and

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[8] See for example *The Top American Research Universities:* Annual Report from the Lombardi Program on Measuring University Performance (The Center, University of Florida, 2002).

resources, or private universities whose private donors provide more financial support, have a relative advantage in competing for quality.

Equally or perhaps more importantly, the U.S. system of higher education is strong largely because it is neither rigidly planned nor hierarchically controlled. The U.S. has some 3,600 colleges and universities with different missions, goals and sources of support. A pecking order gives some few dozen universities widespread recognition, but literally scores of universities and colleges offer students the opportunity to obtain an outstanding undergraduate education. Large numbers of successful scientists and business leaders, for example, began their education at liberal arts colleges or little-known public universities before enrolling in graduate school at a major research university. Of equal significance, a number of universities not in the top tier nevertheless lead particular fields of research or education, and are recognized for peaks of excellence.

3. Mission Changes

All universities have experienced rapid changes in the last two or three decades. The changes that have most contributed to the growth and effectiveness of the research university system include:

- Research universities have become the mandatory gateway and foundation of every major profession.
- The mission of research universities has become more than education. It also has come to entail generating knowledge, disseminating knowledge, and serving the community, region, and the nation. Because of this multifold mission, universities continue to have a major impact on the local, national, and international economies.
- Research, especially in the sciences and engineering, has undergone significant expansion, and has become a key indicator of institutional ranking among peers.
- Universities make social mobility and diversity hallmarks of their missions, which serves to attract foreign students and researchers.

4. Mechanisms Employed

If competition is a means of achieving the goal of excellence, what tried and proven tools or mechanisms best serve this goal? The following are of special importance:

- The U.S. federal government, the biggest single funder of university research, insists in most cases on only funding projects and programs selected by tough and independent peer review. It bases funding on merit, not ranking or history.
- Within institutions, standing and promotion derive from accomplishments, not age or past history.
- The constant movement of researchers and faculty among universities, industry, and government keeps the system and the research undertaken dynamic.
- Adoption of a more or less universal set of metrics and an unofficial ranking system based on these measurements increases competitive spirit and actions.

5. Funding of the System

The complete higher education system in the U.S., which includes community colleges, four-year undergraduate schools, and public and private universities, is a $277-billion enterprise that comprises 2.8 percent of U.S. gross national product. The funding of this system is diverse and constantly shifting. Funding comes from student tuition and fees, state budgets, federal funding of R&D, endowments and gifts, industry support of research and instrumentation, and sources of self-support like real-estate development, and operation of public institutions in health, national laboratories and other public areas.

Federal funding for research conducted at universities is subject to the strategic priorities of the government at a particular time, as is funding from the private sector. The universities, meanwhile, must provide the funding needed to assure that all disciplines and activities needed in a university are properly addressed and balanced.

6. Outlook

Projecting how the U.S. research university system will develop is a dangerous task. One thing is certain: It will continue to change. Six forces in particular will drive these changes.

One: The competition from non-traditional sources in education and perhaps in research will drive change. With today's communication devices, and teaching material available for download (such as MIT course material), new institutions will offer degree courses, even in science and engineering. Universities themselves are providing distance-learning offerings. For example, the English Open University is trying to establish a foothold in the U.S., and such not-for-profit companies as Phoenix University are increasing both offerings and presence.

Two: For the next few years, government spending, both federal and state, may not be as generous as it has been recently. This decline will put extra stress on universities. They will have to make hard decisions about what they want to pursue and what to de-emphasize or drop.

Three: The worldwide source of talent will, in all probability, not be available to the same extent. Academic institutions have depended on foreign students and faculty to fill graduate schools and teaching and research positions. The economy has also benefited from the influx of these people, since many elect to stay here after their studies are complete and join the workforce. Many of the counties that were the source of this talent, however, have been building their industrial and intellectual bases. They will increasingly succeed in keeping or attracting back people that otherwise would have emigrated or stayed in the U.S. Further, the needed emphasis on homeland security is tightening immigration regulations and increasing surveillance of foreign visitors and students. This change will dampen immigration into the country and affect academic institutions as well as the private sector.

Four: The increasing spread of the life sciences continues to place stress upon the structure of universities and their resources. The life sciences remain an extraordinarily promising area. Their promise arises because of the fundamental understanding acquired in the last four decades as well as the rapid development and equally rapid deployment of IT. To take advantage of the resulting potential, universities need new facilities, new organizational entities, and people trained in these disciplines. Doing so will require that universities look at their classical structure of existing departments and schools and decide if their continuance is justified.

Five: The links between industry and academia in the sciences, engineering and business management will increase. More and more of the basic research that industrial laboratories at one time conducted continues migrating to universities, along with people and sometimes the related equipment. Companies expect, in return, to receive new discoveries that can form the basis of their product development. The issue of intellectual property and ownership often arises. Both industry and universities have expectations which can conflict. Working relationships have developed, however, to become "win-win" situations. But strains on both sides continue because each partner wants to maintain its culture and independence. In many instances, industry specifically wants value received from monies spent on universities.

Six: The next century will be more influenced by S&T than the previous one. The pace of S&T discoveries and innovation continues to increase as its value becomes further recognized, new methods and tools become available, and new fields emerge. S&T has assumed an essential role in creating jobs, building new industries, and improving old companies. With the intensification of global problems such as climate change, pollution, poverty, hunger, and disease, scientists and engineers will be called upon to contribute solutions more than ever before. U.S. research universities are poised to play a major role in these developments, and indeed are even more prepared to do so than in the last half century. The hope is that many nations will benefit from their S&T, especially if academic institutions in other countries become as heavily involved in such work as their counterparts in the U.S. As U.S. universities address the changes and challenges ahead, so will the institutions in other nations. The result can and should be growth in the pool of knowledge and in the many other powerful positive benefits that result from the work of great research universities.

Appendix I: Analysis of Sources of Funding for University Research

1. Introduction

The Washington Advisory Group's contract asks for an analysis of the sources of funding for U.S. university research and a view of the opportunities and liabilities this funding entails. The main text of this report summarizes the more important aspect of this topic. We therefore provide in this Appendix details that respond to the questions posed.

2. Trends in National R&D Funding[9]

Overall: Investment in R&D in the United States has increased steadily since the mid-1970's in real terms.[10] There were periods of fast growth in the first half of the 1980's and the last half of the 1990's and a small downturn in 1993 and 1994 (Figure I-1).

In 2000, national investment in R&D was $265 billion, compared with $152 billion in 1990, an increase of nearly 41 percent in real terms. Increases from 1995-2000 were greater, between 5.4 percent and 6.2 percent annually.

Sources of National R&D Funding: Most of the increase in funding of R&D has come from industry (Figure I-1).[11] For example, industry funding of R&D increased by 328 percent from 1975 to 2000 in real terms, compared with an increase in federal R&D funding of 41 percent over the same period. In the 1970's industry and government funding for R&D were at par; the amount of industry funding of R&D began to surpass the federal government's in 1980.

The increase in R&D funding from sources other than industry and the federal government, especially from the universities and colleges themselves as well as from state budgets, was also substantial. We have more to say about this subject below.

During the 1990's, the gap between industry and federal investment widened quickly. While industry was investing more in R&D, federal funding was essentially flat (Figure I-2). As a result, industry accounted for 68 percent and the federal government for 26 percent of the total in 2000, compared with 55 percent and 41 percent, respectively, in 1990 (Figure I-3).

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[9] Data in this section and the related Figures I-1 through I-7 are from *National Patterns of R&D Resources: 2000 Data Update* (NSF, 2001) adjusted for inflation.
[10] In this analysis, the GDP implicit price deflator is used to determine real changes.
[11] Because of beneficial tax treatment of industrial R&D and lack of technical strength in the Internal Revenue Service, industry figures may be somewhat overstated.

Performers of National R&D: R&D performed by industry (i.e., conducted in-house) has increased substantially (Figure I-4), as has academic R&D, the latter by 190 percent. Funding for federal intramural R&D increased much less during the same period, by 29 percent. As a result, industry's performance of R&D has increased from 68 percent of the national total in 1975 to nearly 76 percent in 2000 (Figure I-5). Federal intramural R&D was seven percent in 2000, compared with 16 percent in 1975. The academic sector spent about the same percentage of national R&D funding in 2000 as in 1975, between 13 and 14 percent.

Character of Work: Funding of basic research has increased relative to applied research and development since 1975, especially during the 1990's (Figure I-6), although 61 percent of the funding still goes to development in absolute terms (Figure I-7).[12] Basic research accounted for 18 percent of national R&D funding in 2000, compared with 15 percent in 1990 (Figure I-7).

3. Trends in Federal R&D Funding[13]

Overall: The federal government investment in R&D totaled nearly $81 billion in 2002, compared with $48 billion in 1975 and $64 billion in 1990 (in current dollars). In real terms, however, the 2002 amount was two percent less than in 1990 (Figure I-8). This decrease, however, marked an improvement from the mid-1990's. During the first half of the 1990's, federal funding of R&D fell. Since 1996, the trend has been generally positive.

Although the level of funding was basically the same in 2002 as in 1990 in real terms, there have been significant shifts in funding by agency; in the balance between basic research, applied research, and development; in the balance among R&D performers; and in funding by field of science and engineering, which is described in the following sections.

Sources of Funding: In the period from 1990-2002, DOD funding of R&D shrunk by 29 percent in real terms (Figure I-9). Two other major R&D agencies, DOE and NASA, also reduced R&D funding, by 13 percent and 14 percent, respectively. Most of the net reduction in R&D funded by those agencies has been offset by increases in NIH funding, whose R&D budget

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[12] A sizeable amount of the development figure is military expenditures.
[13] Data in this section and the related Figures I-8 through I-15 are taken from Federal Funds for Research and Development, a database updated annually by the NSF.

increased by 138 percent during the same time period. To a lesser extent, NSF's budget also increased.

Character of Work: Federal funding of research increased relative to development in the 1990's, in part because DOD reductions in R&D occurred mostly in development programs and in part because most of the growth in R&D from 1990-2002 occurred in basic and applied research at NIH. Federal funding of basic and applied research increased while federal development funding fell (Figure I-10). As a result, development work constituted 44 percent of federal R&D in 2002, compared with 66 percent in 1990 (Figure I-11). It should be noted, however, that while federal funding of basic and applied research has increased steadily for a long time, development funding has experienced large ups and downs, notably affecting industry as a performer (Figures I-12 and I-13).

Performers of Federal R&D: Universities and other nonprofit institutions have conducted an increasing amount of federally funded R&D and, by 2002, performed substantially more R&D than in 1975—161 percent and 99 percent more, respectively (Figure I-13). This trend towards federal funding of R&D in academia parallels the shift from development to basic and applied research.

Broad Fields of Science and Engineering Research: Federal support of research in the life sciences has grown steadily over the past 20 years (by 301 percent) in real terms, and the rate of increase accelerated in the latter half of the 1990's (Figure I-14).[14] Federal funding of the mathematical and computer sciences, driven mostly by investments in computer science research, also grew substantially from 1970-2002 (by 617 percent). As funding for the life sciences increased, so did increases for psychology research (402 percent). The other fields also received real increases over the time period, but these were much smaller. Engineering and the physical sciences grew by 41 percent and 19 percent, respectively.

In 2002, the life sciences accounted for 49 percent of federal research funding, up from 29 percent in 1970 (Figure I-15). Despite strong growth, the math/computer sciences and

[14] Funding by field of science and engineering is only reported for basic and applied research, not for development funding.

psychology started from a relatively small base and accounted, respectively, for just six percent and five percent of the funding in 2002. Engineering and physical sciences received 16 percent and 11 percent of federal science funding in 2002, respectively, compared with 31 percent and 19 percent in 1970.

4. Trends in Academic R&D[15]

Overall: Expenditures for R&D by universities and colleges have increased in real terms almost every year since they were first tracked in the early 1950's (Figure I-16).[16] They totaled more than $30 billion in 2000, real increases of 230 percent since 1975 and 49 percent since 1990.

Sources of Academic R&D Funding: In 2000, universities and colleges reported that the federal government provided more than $17 billion for R&D. State/local governments and industry provided $2.2 billion each. Universities and colleges spent $5.9 billion from their own institutional funds, namely tuition, endowment, and other revenues. Other sources, such as foundations, provided another $2.3 billion.

All sources of academic R&D have increased substantially in real terms (Figure I-16). Funding from institutional funds, industry, and other sources has increased the fastest, but the federal government still provides the majority of academic R&D funding. The federal share was 58 percent in 2000, down from 73 percent in the mid-1960's (Figure I-17).

Character of Work: Basic-research funding increased steeply from 1953 to 1968, and then leveled off until 1977, when it began to grow again, including high growth periods in the latter half of the 1980's and the latter half of the 1990's (Figure I-18). The growth curve for academic applied research and development has been steadier but generally not as steep. In percentage terms, the amount of university R&D funding devoted to basic research peaked in 1964 at 79 percent (Figure I-19). It has been less than 70 percent since 1976, but has increased its share from a low of 65 percent in 1990 to 69 percent in 2000.

[15] Data in this section and the related Figures I-16 through I-19 are taken from Academic Research and Development Expenditures, a database updated annually by the NSF, based on surveys of universities and colleges.

5. Trends in Research Funding by Field of Science and Engineering[17]

Funding for research conducted at universities and colleges totaled $30 billion in 2000, a real increase of 160 percent from 1980-2000 and 49 percent from 1990-2000 (Fig. I-16). These increases were not uniform by field and the pattern in the 1990's was different than in the 1980's. At the broad field level, for example, the life sciences experienced steady growth during both decades, with especially strong growth during the last part of the 1990's (reflecting 15 percent increases in the funding of NIH in 1999 and 2000, the first two years of the campaign mentioned in the main text to double federal funding of NIH) (Figure I-20). Psychology and the social sciences also fared significantly better in the 1990's than in the 1980's, but respectable growth in engineering and physical sciences research in the 1980's (50 percent and 42 percent, respectively) did not extend into the 1990's, although growth began to accelerate some during the last few years of the decade. Real growth in those two broad fields was 38 percent and 21 percent, respectively, in the 1990's.

The same pattern emerges at the fine field level (Figure I-21). Certain fields that did well in the 1980's, most of them in the physical sciences and engineering, did much less well in the 1990's in terms of funding growth. These fields, which are shown on the left side of the graph, included physics, chemistry, mathematics, and aeronautical and astronautical engineering. Several fields with medium funding increases in the 1990's, as shown in the middle of the graph, had done even better in the 1980's. These fields included electrical engineering, computer sciences, and chemical engineering. Some of the fields whose funding increased the most in the 1990's, as shown on the right side of the graph, had also received substantial increases in the 1980's, including the medical and biological sciences, astronomy, and civil engineering.

The trends in academic research funding by field were driven by the shifts in federal funding among fields that the previous section described. Generally speaking, however, trends in non-federal funding of academic research reinforced rather than moderated the shifts in federal funding. For example, many of the fields receiving large increases in federal funding in the 1990's also received relatively large increases from non-federal sources (compare Figures I-21 and I-22). These fields included astronomy, medical and biological sciences, civil engineering, and psychology. Some fields that experienced much smaller increases from federal agencies in

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[16] There were real decreases in 1969, 1970, and 1974.

the 1990's than in the 1980's, including physics, chemistry, and mathematics, also received smaller increases from non-federal sources. Electrical engineering and the computer sciences, which had received among the largest increases in funding in the 1980's from both federal and non-federal sources, received only medium increases from both sectors in the 1990's.

[17] Data in this section and the related Figures I-20 through I-23 are taken from Academic Research and Development Expenditures, a database updated annually by the NSF, based on surveys of universities and colleges.

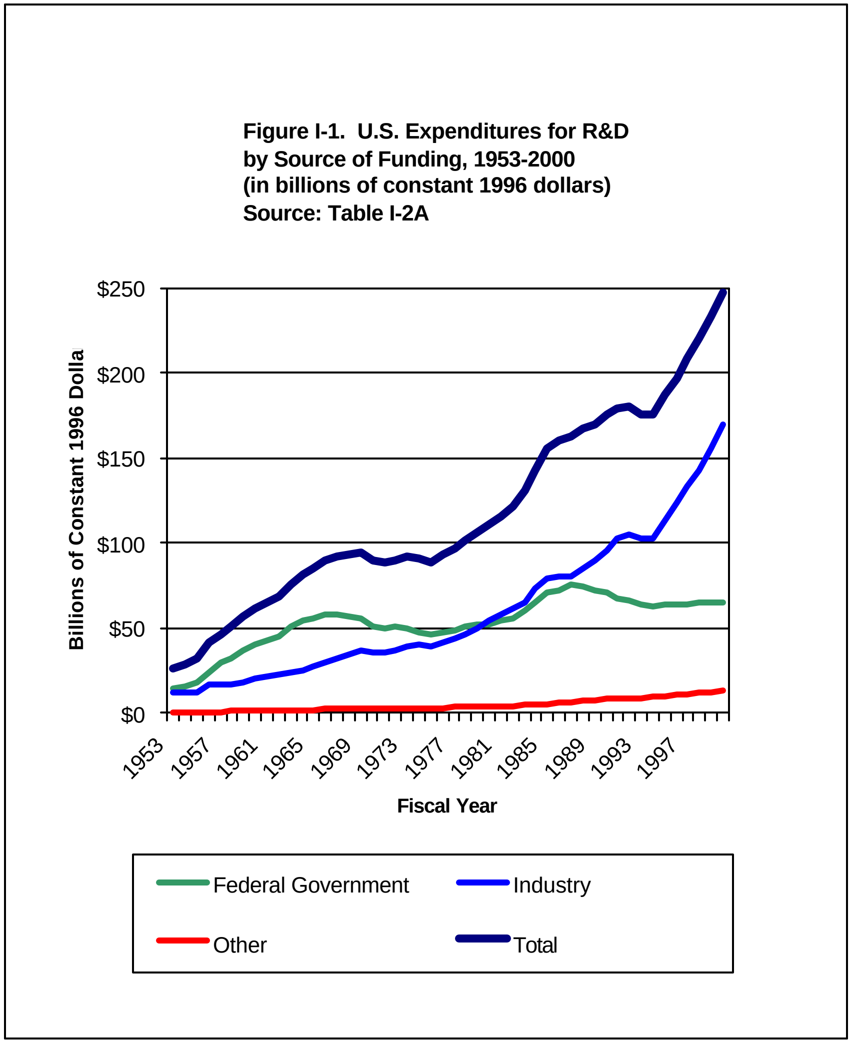


Figure I-1. U.S. Expenditures for R&D
by Source of Funding, 1953-2000
(in billions of constant 1996 dollars)
Source: Table I-2A
Billions of Constant 1996 Dolla
$250
$200
$150
$100
$50
$0
1953
1957
1961
1965
1969
1973
1977
1981
1985
1989
1993
1997
Fiscal Year
Federal Government
Industry
Other
Total

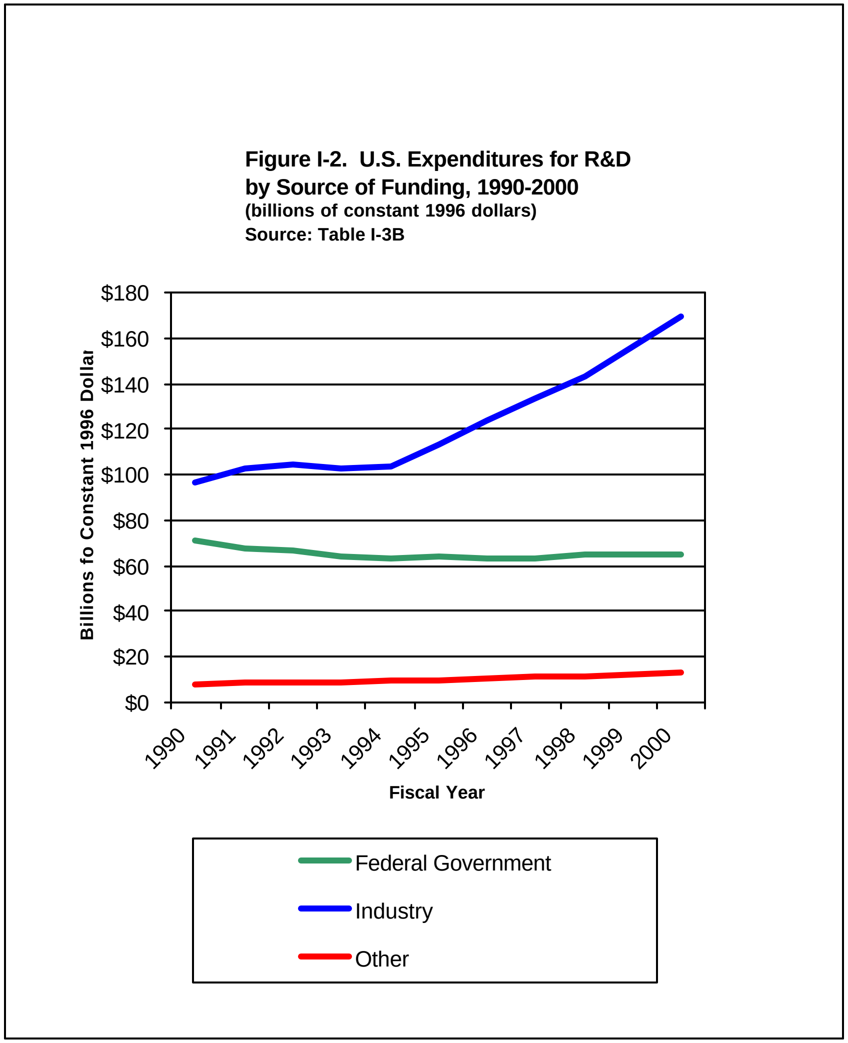


Figure I-2. U.S. Expenditures for R&D
by Source of Funding, 1990-2000
(billions of constant 1996 dollars)
Source: Table I-3B
Billions fo Constant 1996 Dollar
$180
$160
$140
$120
$100
$80
$60
$40
$20
$0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Fiscal Year
Federal Government
Industry
Other

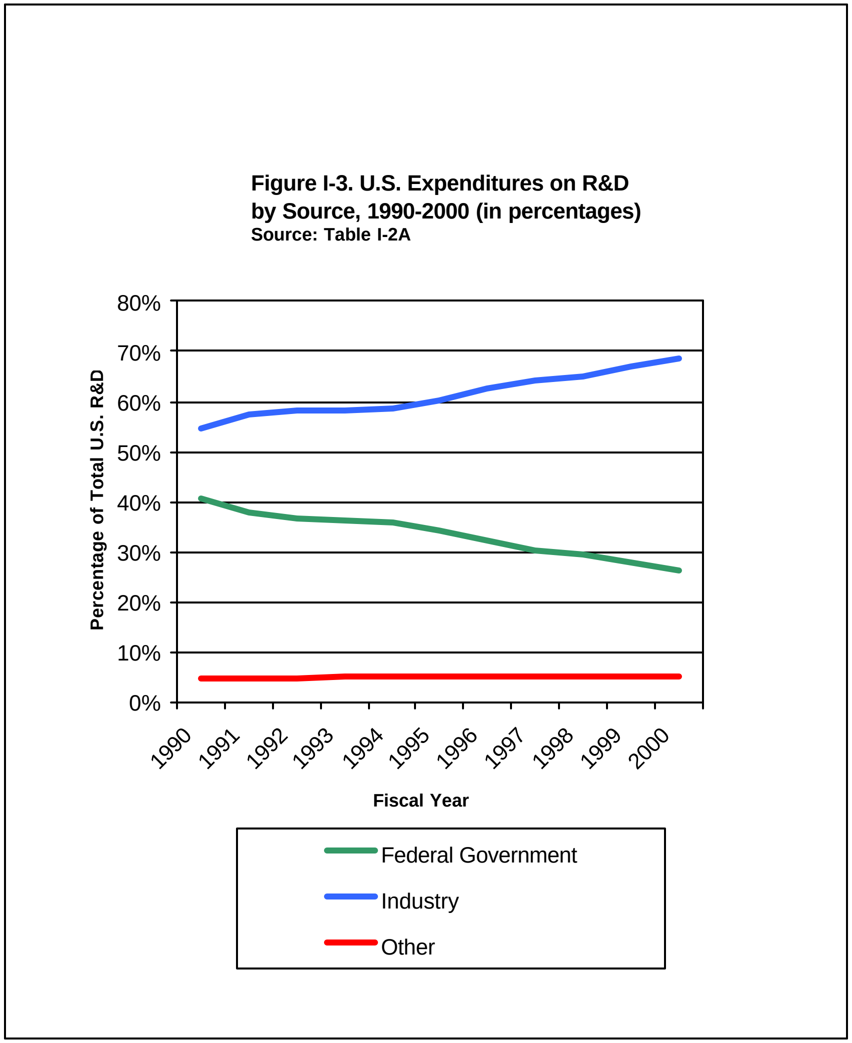


Figure I-3. U.S. Expenditures on R&D
by Source, 1990-2000 (in percentages)
Source: Table I-2A
Percentage of Total U.S. R&D
80%
70%
60%
50%
40%
30%
20%
10%
0%
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Fiscal Year
Federal Government
Industry
Other

Figure I-4. U.S. Expenditures on R&D by Performer, 1953-2000 (in billions of constant 1996 dollars) Source: Table I-3A

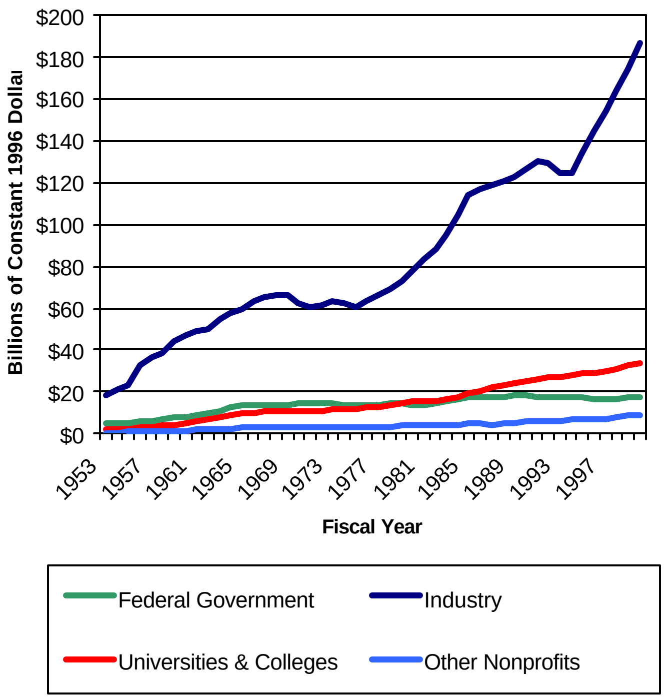


Figure I-5. U.S. Expenditures for R&D by Performer, 1953-2000 (in percentages) Source: Table I-3A

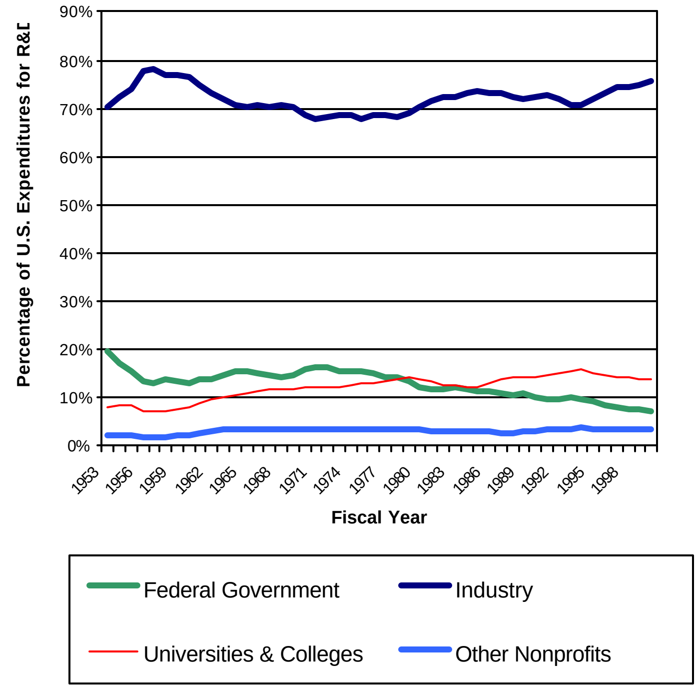


Figure I-6. U.S. Expenditures on R&D by Character of Work,1953-2000 (in billions of constant 1996 dollars) Source: Table I-4A

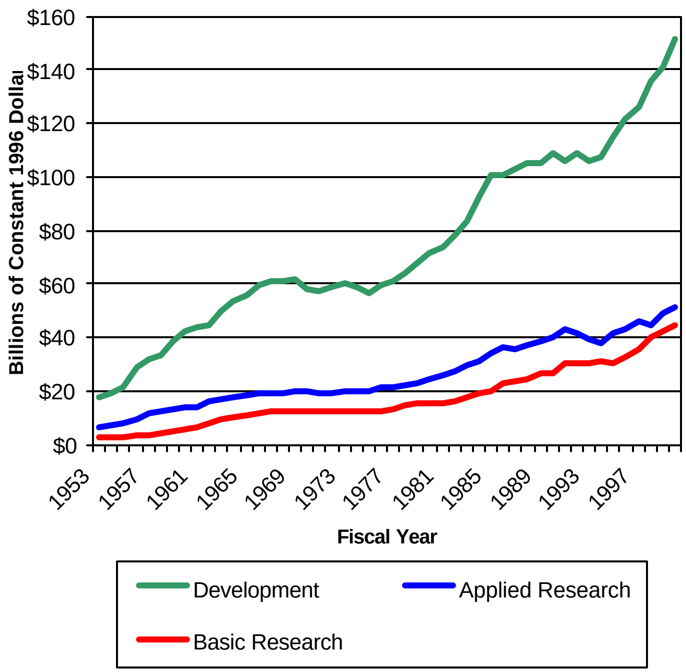


Figure I-7. U.S. Expenditures for R&D by Character of Work, 1953-2000 (in percentages) Source: Table I-4A

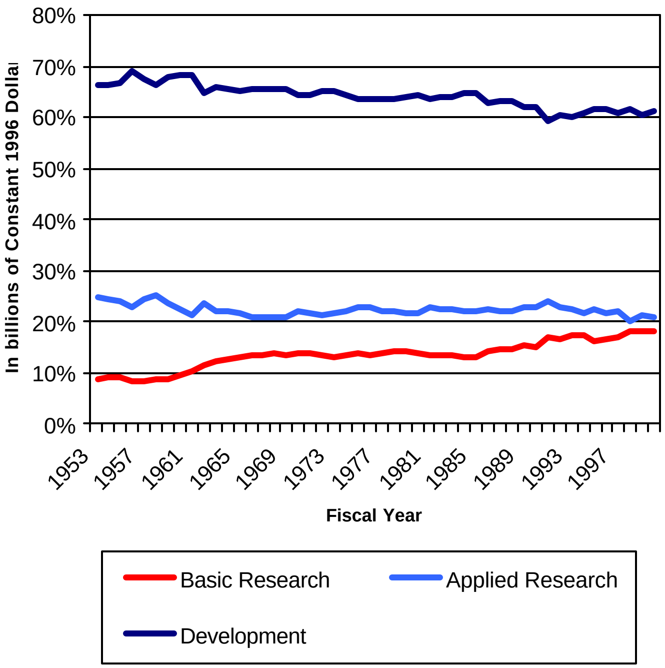


Figure I-8. Federal Obligations for R&D, 1970-2002
(in billions of constant 1996 dollars)
Source: Table II-1B

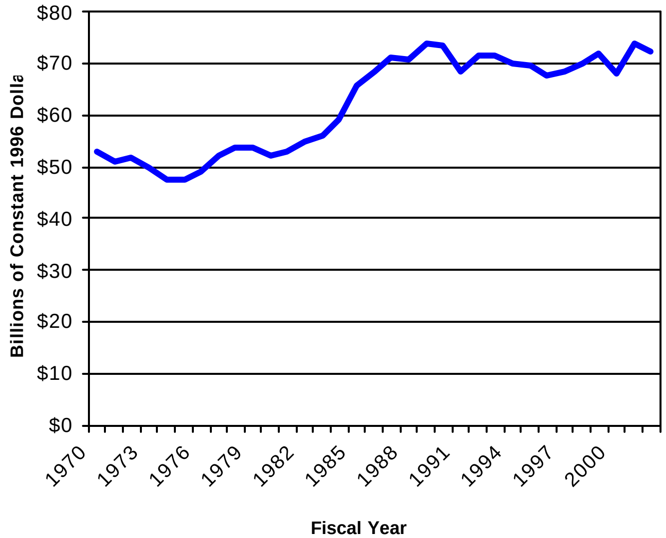


Figure I-9. Federal Obligations for R&D by Five Largest R&D Agencies, 1990-2002 (in billions of constant 1996 dollars)
Source: Table II-1B

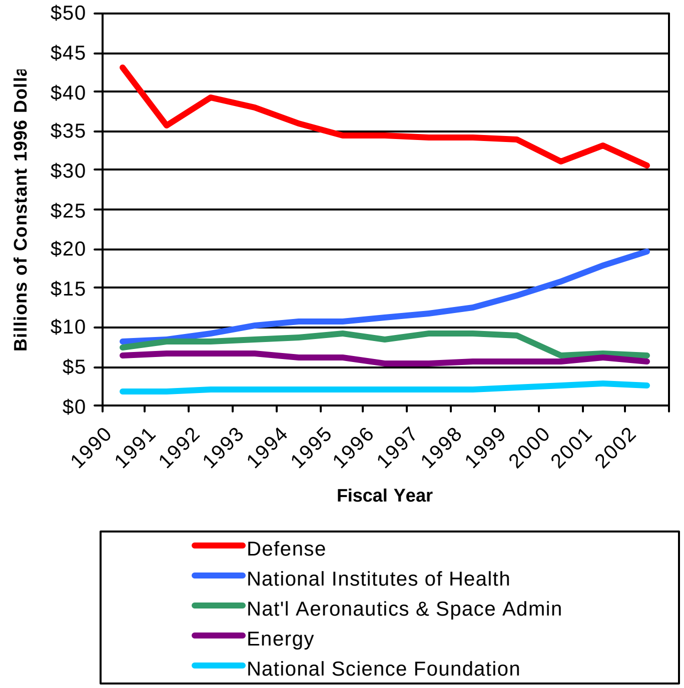


Figure I-10. Federal Obligations for R&D
by Character of Work, 1990-2002
(in billions of constant 1996 dollars)
Source: Table II-2C

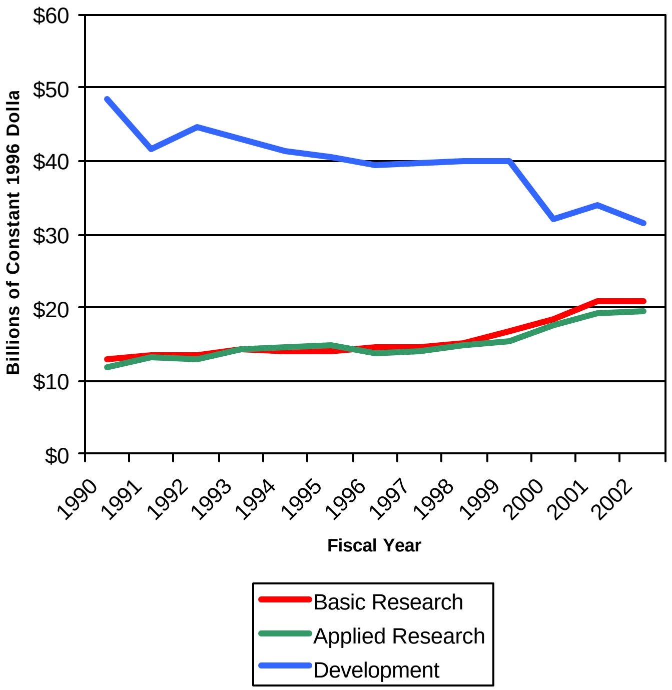
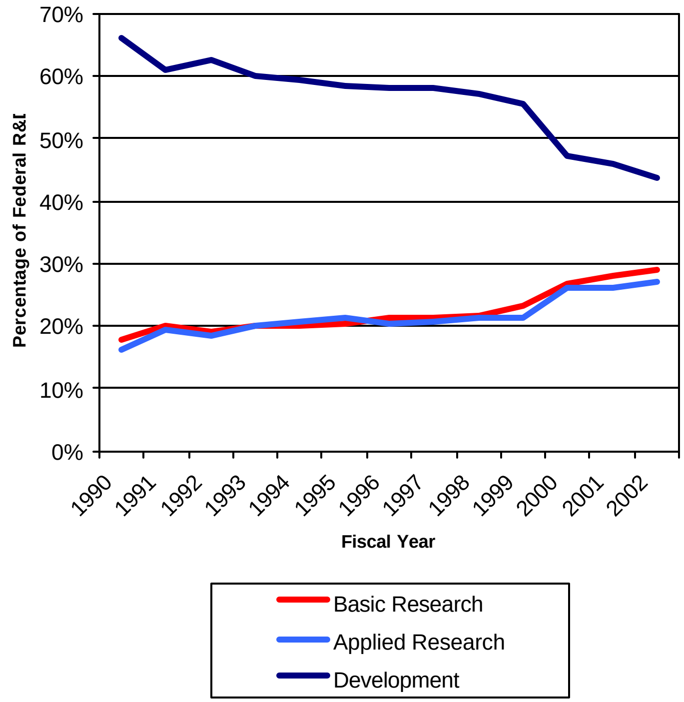


Figure I-11. Federal Obligations for R&D
by Character of Work, 1990-2002
(in percentages)
Source: Table II-2B



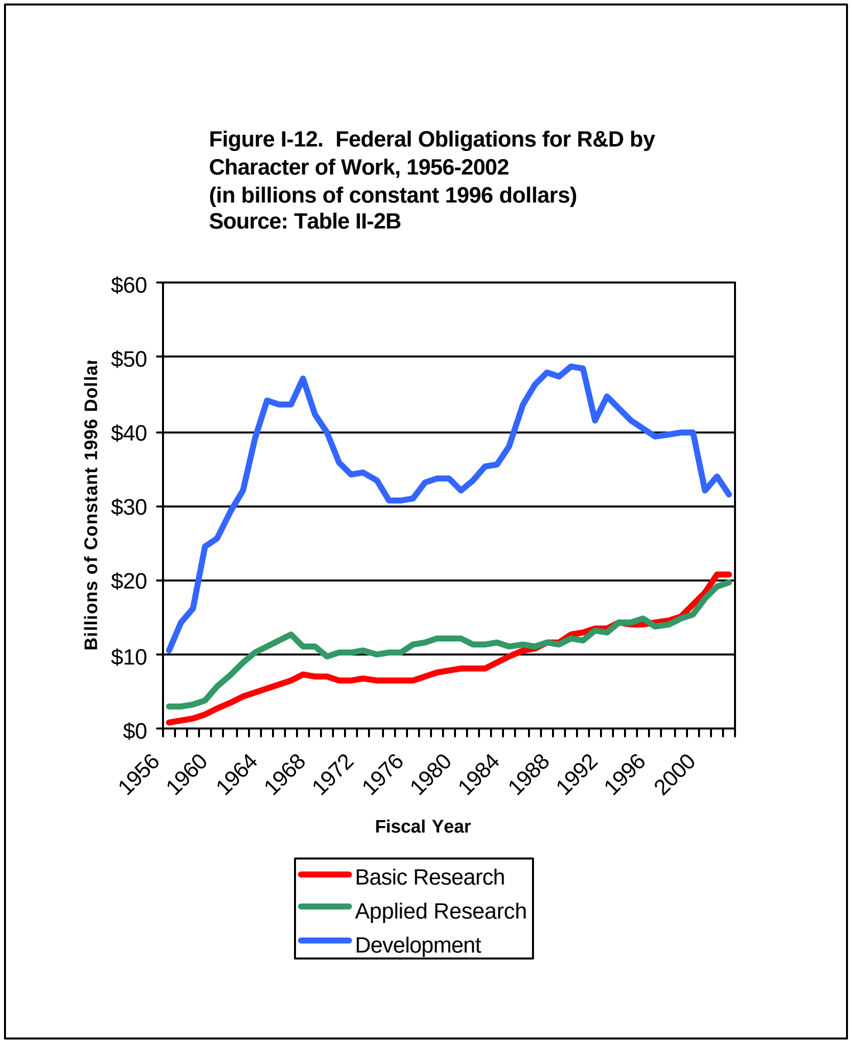


Figure I-12. Federal Obligations for R&D by
Character of Work, 1956-2002
(in billions of constant 1996 dollars)
Source: Table II-2B
Billions of Constant 1996 Dollar
$60
$50
$40
$30
$20
$10
$0
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
Fiscal Year
Basic Research
Applied Research
Development

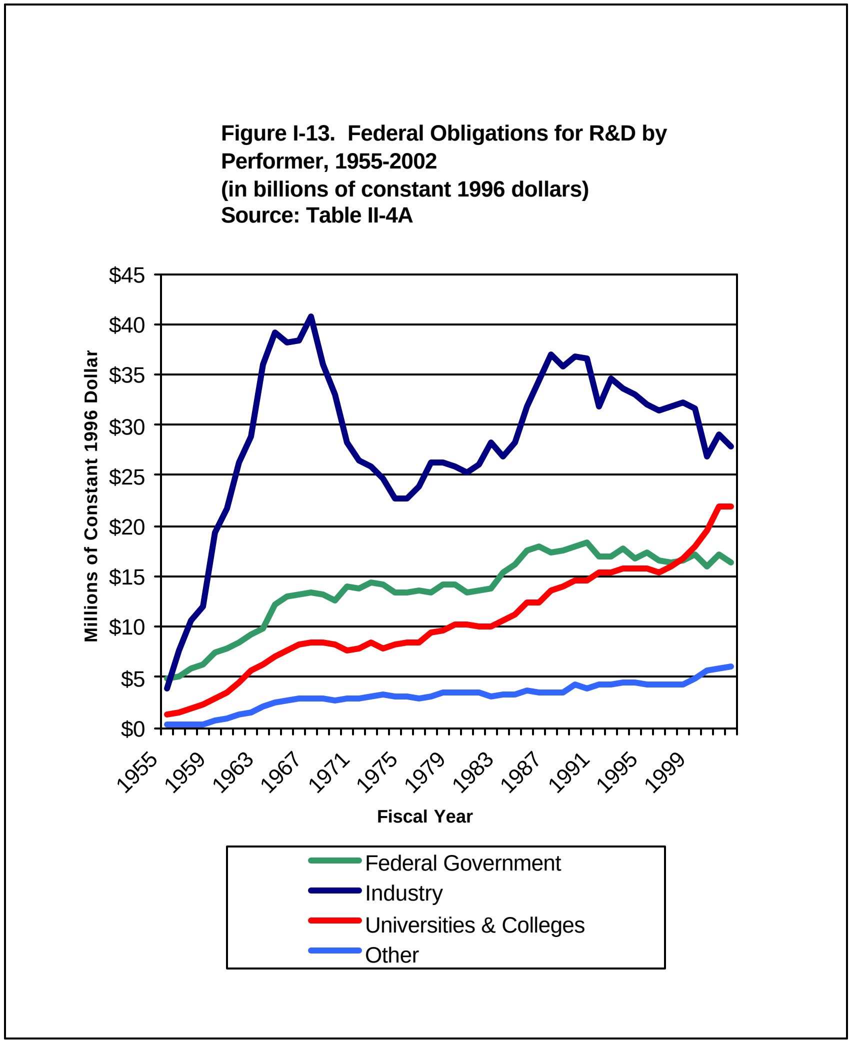


Figure I-13. Federal Obligations for R&D by
Performer, 1955-2002
(in billions of constant 1996 dollars)
Source: Table II-4A
Millions of Constant 1996 Dollar
$45
$40
$35
$30
$25
$20
$15
$10
$5
$0
1955
1959
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Fiscal Year
Federal Government
Industry
Universities & Colleges
Other

Figure I-14. Federal Obligations for Research by Field of Science and Engineering, 1970-2002 (in billions of constant 1996 dollars)
Source: Table II-5B

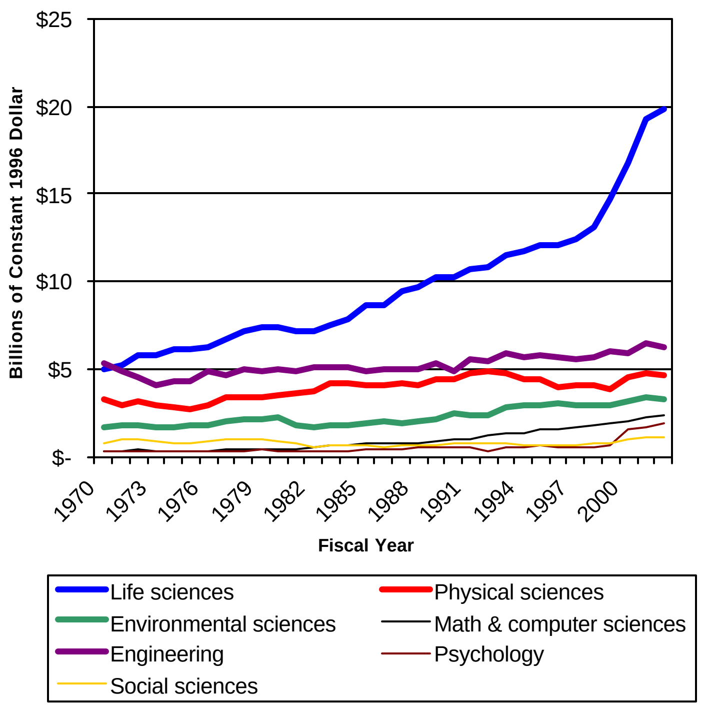


Figure I-15. Federal Obligations for Research by Field of Science and Engineering, 1970-2002 (in percentages)
Source: Table II-5B

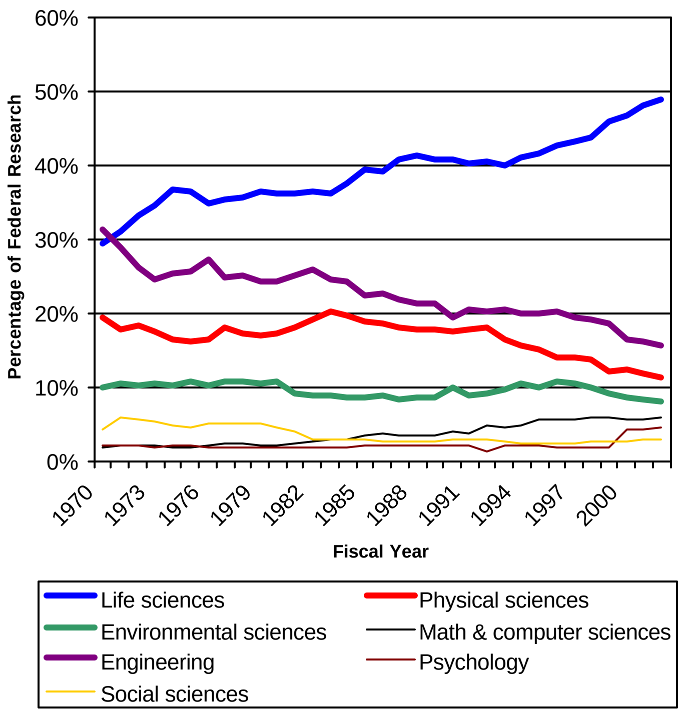


Figure I-16. Academic Expenditures for R&D by Source of Funding, 1953-2000 (in billions of constant 1996 dollars)
Source: Table III-2A

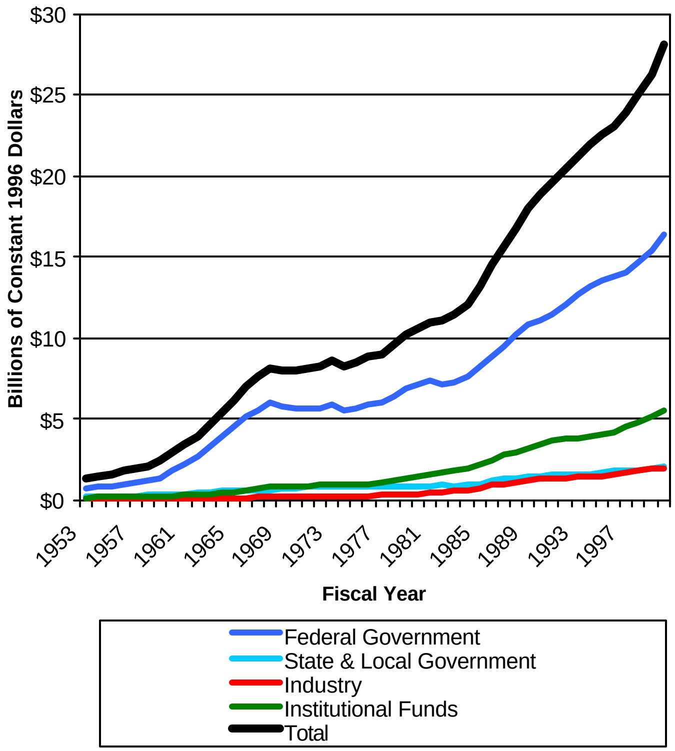


Figure I-17. Academic Expenditures for R&D by Sources of Funding, 1953-2000 (in percentages)
Source: Table III-2A

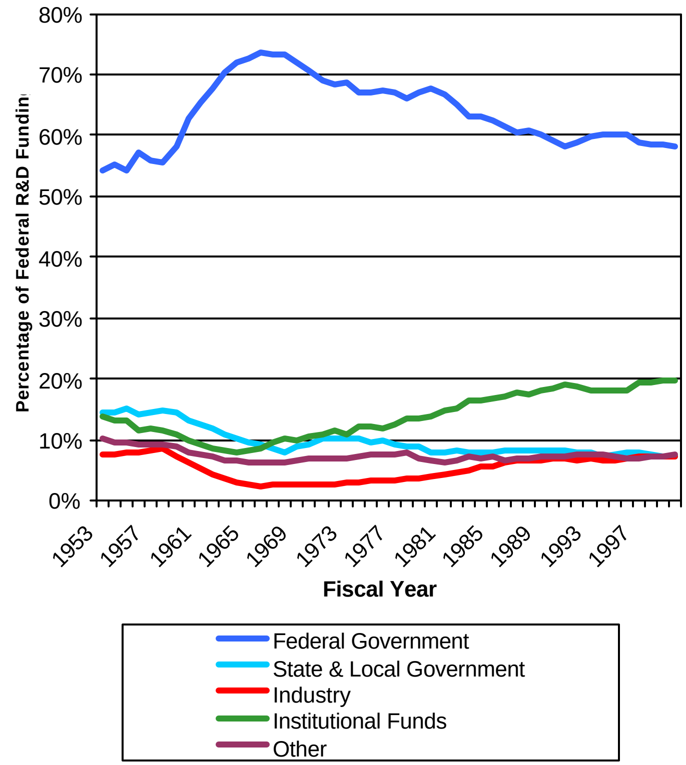


Figure I-18. Academic Expenditures for R&D by Character of work, 1953-2000 (in millions of constant 1996 dollars) Source: Table III-4A

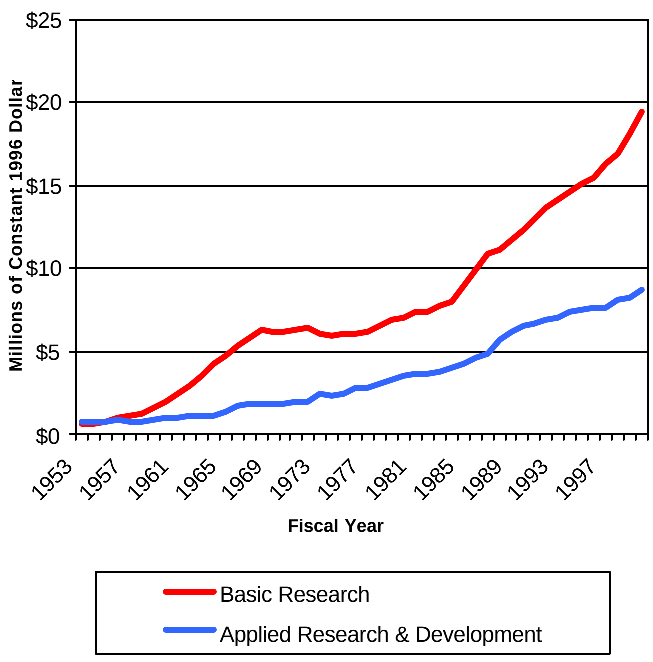


Figure I-19. Academic Expenditures for R&D by Character of Work, 1953-2000 (in percentages) Source: Table III-4A

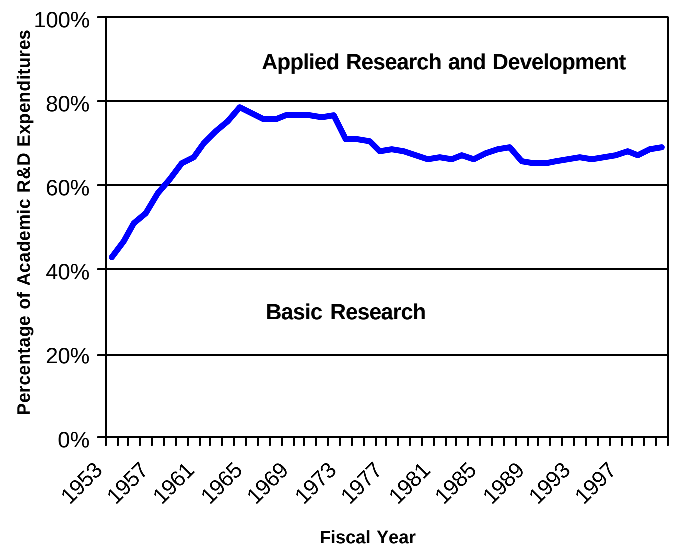
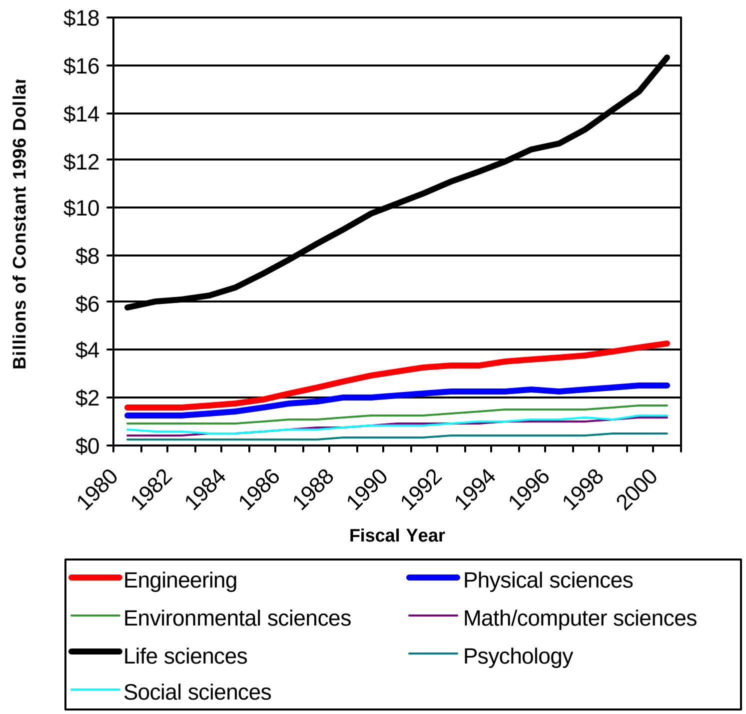


Figure I-20. Expenditures for Academic R&D by Broad Field, 1980-2000 (in billions of constant 1996 dollars) Source: Table IV-1B



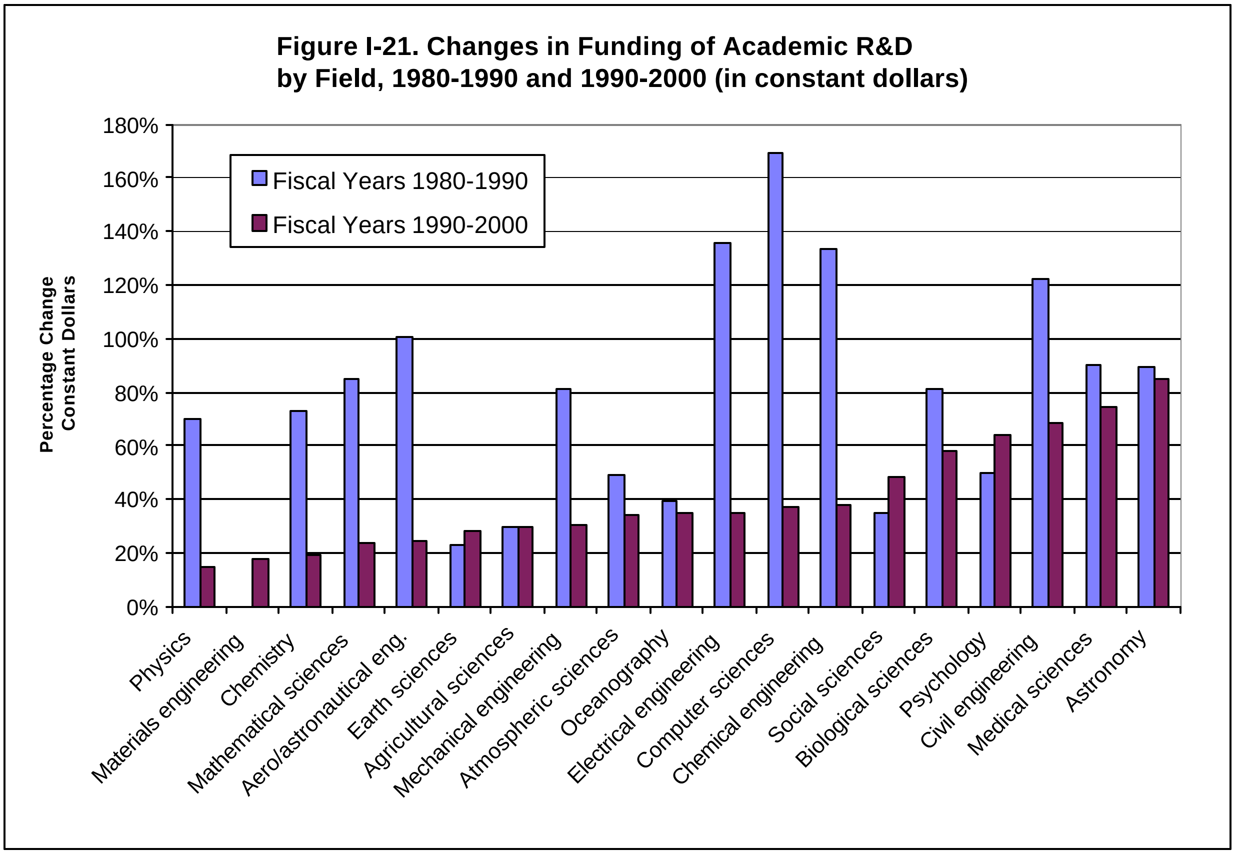


Figure I-21. Changes in Funding of Academic R&D
by Field, 1980-1990 and 1990-2000 (in constant dollars)
Percentage Change
Constant Dollars
Fiscal Years 1980-1990
Fiscal Years 1990-2000
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
Physics
Materials engineering
Chemistry
Mathematical sciences
Aero/astronautical eng.
Earth sciences
Agricultural sciences
Mechanical engineering
Atmospheric sciences
Oceanography
Electrical engineering
Computer sciences
Chemical engineering
Social sciences
Biological sciences
Psychology
Civil engineering
Medical sciences
Astronomy

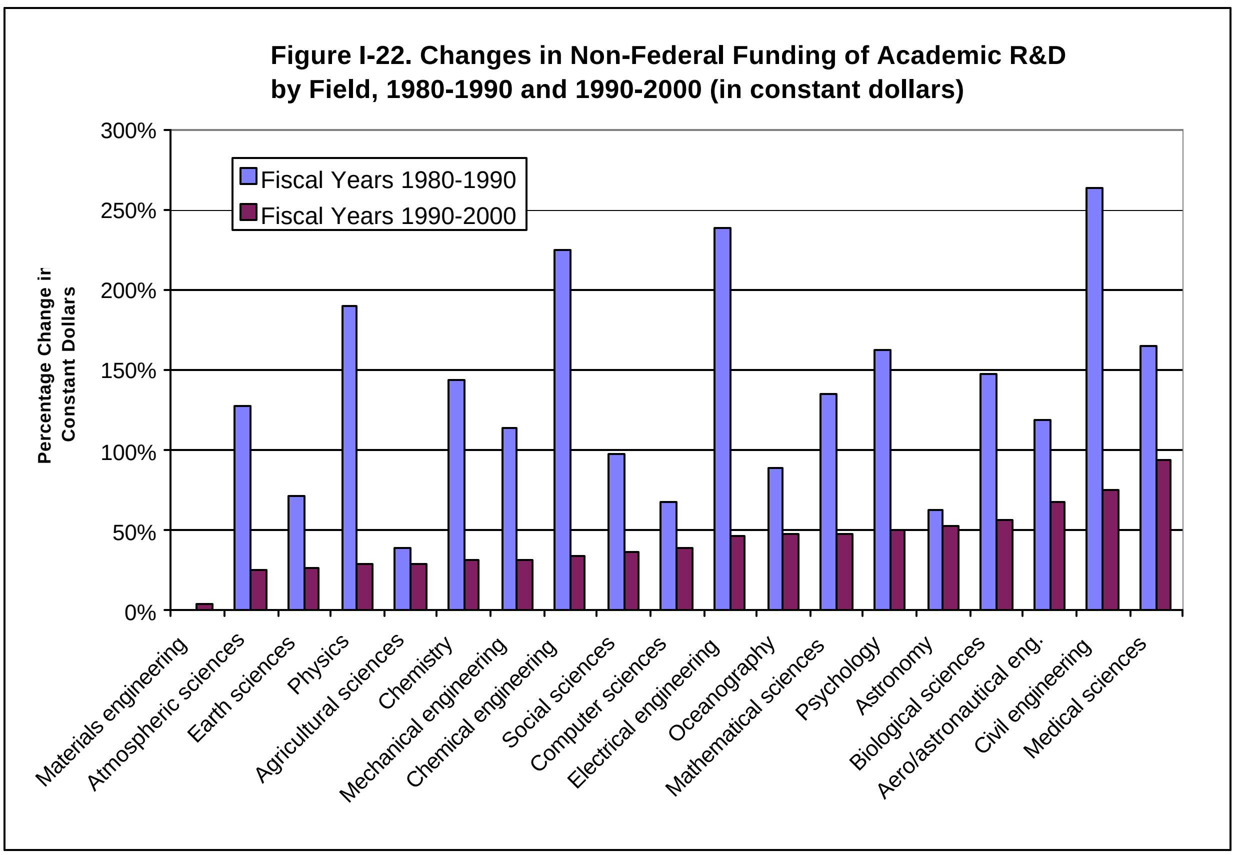
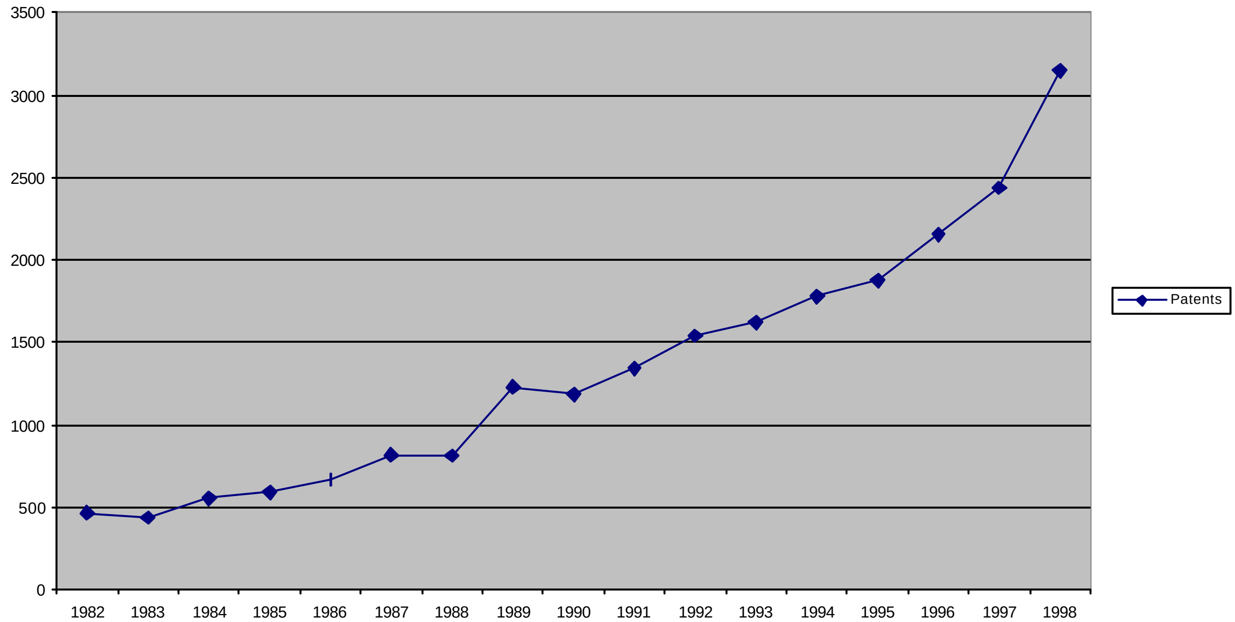
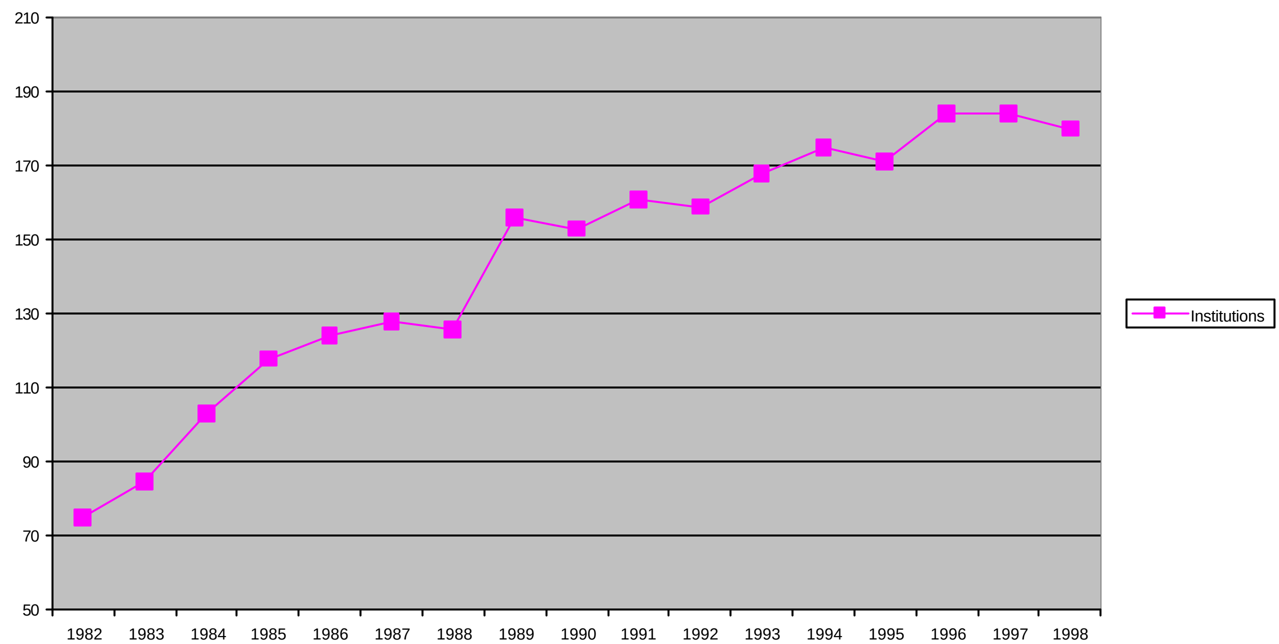


Figure I-22. Changes in Non-Federal Funding of Academic R&D
by Field, 1980-1990 and 1990-2000 (in constant dollars)
Percentage Change in
Constant Dollars
Fiscal Years 1980-1990
Fiscal Years 1990-2000
300%
250%
200%
150%
100%
50%
0%
Materials engineering
Atmospheric sciences
Earth sciences
Physics
Agricultural sciences
Chemistry
Mechanical engineering
Chemical engineering
Social sciences
Computer sciences
Electrical engineering
Oceanography
Mathematical sciences
Psychology
Astronomy
Biological sciences
Aero/astronautical eng.
Civil engineering
Medical sciences

Figure I-23. U.S. Patents Granted to Academic Institutions and Academic Institutions Receiving Patents, 1982-1998





Appendix II: Suggested Sources for Additional Information

General

Council on Competitiveness. *Endless Frontier, Limited Resources: U. S. R&D Policy for Competitiveness*. Washington, DC: Council on Competitiveness (April 1996).

Daedalus, Journal of the American Academy of Arts and Sciences. *The American Research University*. Cambridge, MA: American Academy of Arts and Sciences (Fall 1993).

Geiger, Roger L. *Research and Relevant Knowledge: American Research Universities Since World War II*. New York, NY: Oxford University Press (1993).

National Institutes of Health, Office of Extramural Research (OER). *OER: Peer Review Policy and Issues* (web page with links to documents relevant to the peer review process for NIH grant decisions) http://grants1.nih.gov/grants/peer/peer.htm

National Science Foundation. *Grant Proposal Guide*. Arlington, VA: The National Science Foundation (October 2002). (NSF 03-2). http://www.nsf.gov/pubs/2003/nsf032/gpg032.pdf

Rhodes, Frank H.T. *The Creation of the Future: The Role of the American University*. Ithaca, NY: Cornell University (2001).

Rhodes, Frank H.T. (Ed.). *Successful Fund Raising for Higher Education: The Advancement of Learning*. Phoenix, AZ: The American Council on Education and The Oryx Press (1997).

United States General Accounting Office. *Federal Research: Peer Review Practices at Federal Science Agencies Vary*. Washington, DC: U.S. General Accounting Office (March 1999). (GAO/RCED-99-99). http://www.gao.gov/

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Eiseman, et. al. *Federal Investment in R&D.* Arlington, VA: RAND (September 2002). (MR-1639.0-OSTP) http://www.rand.org/publications/MR/MR1639.0/

Lombardi, John V., et.al. *The Top American Research Universities (An Annual Report from* The Lombardi Program on Measuring University Performance). Gainesville, FL: The Center (2002). http://thecenter.ufl.edu/research2002.html

National Academies of Sciences and Engineering, Institute of Medicine, National Research Council. *Allocating Federal Funds for Science and Technology*. Washington, DC: National Academy Press (1995). http://www.nap.edu/catalog/5040.html

National Science Board, *Science and Engineering Indicators—2002.* Arlington, VA: National Science Foundation (2002) (NSB-2-01). http://www.nsf.gov/sbe/srs/seind02/start.htm

U.S. News & World Report's America's Best Colleges 2003 Edition. Washington, DC: U.S. News & World Report LP (2002). http://www.usnews.com/usnews/edu/college/rankings/rankindex_brief.php.

U.S. News & World Report's Best Graduate Schools 2003 Edition. Washington, DC: U.S. News & World Report LP (2002). http://www.usnews.com/usnews/edu/grad/rankings/rankindex.htm

Technology Transfer/Economic Development

Albert, Michael B., et. al. *The New Innovators: Global Patenting Trends in Five Sectors.* Washington, DC: U.S. Department of Commerce, Office of Technology Policy (September 1998). http://www.ta.doc.gov/Reports/09111998.pdf

Engines of Economic Growth: The Economic Impact of Boston's Eight Research Universities on the Metropolitan Boston Area. New York, NY: Appleseed (2003). http://www.masscolleges.org/Economic/pdf/full_report.pdf

MIT: The Impact of Innovation. Boston, MA: BankBoston (1997). http://web.mit.edu/newsoffice/founders/

Stephenson, Frank. "A Tale of Taxol," *Florida State University Research in Review*, Vol. XII, No. 3 (Fall 2002). http://www.research.fsu.edu/researchr/fall2002/taxol.html

Wang, Mark, et. al. *Technology Transfer of Federally Funded R&D*: Perspectives from a Forum. Arlington, VA: RAND (2003). http://www.rand.org/publications/CF/CF187/

Case Study University Websites

Massachusetts Institute of Technology: http://www.mit.edu

Stanford University: http://www.stanford.edu

University of California, San Diego: http://www.ucsd.edu

University of Texas at Austin: http://www.utexas.edu/