UNIVERSITIES IN THE U.S. NATIONAL INNOVATION SYSTEM

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Summary of Main Points

- The U.S. spends approximately 2.7 percent of its GDP on R&D and has done so over each of the last two decades. Development expenditures now account for 60 percent of total R&D. Applied research accounts for 22 percent and basic research for 18 percent.

- While basic research accounts for a relatively small share of total R&D, it figures prominently in the R&D budgets of governments and in debates about public policy toward science and technology. Because of spillovers and an inability to appropriate commercial value from research findings, societies will underinvest in basic research unless it is supported by government.

- Private industry performs over 90 percent of development and about 70 percent of applied research. Basic research, on the other hand, is performed primarily in universities and colleges.

- That almost all of the nation's "D" is done in private industry, and that a majority of its "R" is done at universities, reflects an efficient division of labor. Many university professors are too far from the market and the factory floor to make good commercial judgements in areas of product or process development. Private industry, on the other hand, is not well suited to doing basic research. Industry perspectives are narrow, and firms will have a difficult time appropriating commercial value from basic research findings.

- Universities have several advantages over other organizations in performing basic research and training future researchers. Students can participate in and assist with research production and help transfer research findings to industry. Because of the broad curriculum of coursework available through departments, research universities are good at training new researchers. The academic merit system also helps to promote rapid dissemination of research findings.

- There have been important shifts in the sources of funding U.S. R&D over the past two decades. The federal government has sharply reduced its R&D spending, especially in defense. Total R&D effort has remained unchanged, however, because of offsetting increases in industry funding. Technological spillovers from defense to civilian applications are thought to have been less significant in recent decades than they were in the 1950s and 1960s. It is likely then that the recent shifts in R&D activity have raised the nation's overall investment in generating knowledge that is useful for producing civilian goods.

- Support for academic R&D has increased over the past three decades from 0.22 percent of GDP in the 1970s to 0.30 percent over the last ten years. The share of academic R&D supported by the federal government has fallen from 68 percent to 59 percent. This has been offset primarily by rising contributions from universities and colleges.

- The U.S. devotes 2.7 percent of its GDP to R&D, as compared with an average across all OECD countries of 2.2 percent. Because of the large absolute size of the U.S. economy and the relatively high intensity of its effort, the United States accounts for 43 percent of total R&D in OECD countries. The Unites States also leads all countries by a wide margin in number of articles published in scientific journals, a measure of output of basic research. Compared to other countries, the U.S. places heavy emphasis in its academic research on medical and health science, social science, and the professional fields and relatively light emphasis on chemistry, physics, and engineering.

- Compared with other countries, a relatively large percentage of U.S. basic research is performed at universities by faculty who are also actively involved in education, especially graduate education. The coupling of research and graduate education has helped the U.S. to develop an effective system of technology transfer through their students and to build the premier system of graduate instruction in the world.

- Sources of funding for U.S. basic research are relatively diverse and decentralized. This has allowed universities and other organizations involved in basic research to choose lines of research based on scientific merit, with less consideration for how well the research fits with political agendas of elected officials or the preconceptions of industry sponsors.

- The U.S. university system is highly competitive, involving a large number of heterogeneous institutions, both public and private. Because of competition for research funding, universities must manage costs well and be willing to adjust research portfolios to accommodate shifts in demand. Competition among universities also helps to create a competitive market for scientists and faculty. It is also argued that competition is what enabled the U.S. to create unparalleled excellence in its graduate programs.

- The U.S. has made a serious effort over the past twenty-five years to strengthen intellectual property protection. Most important for universities was the Bayh-Dole Act of 1980 which allowed universities to license patents on research funded by the federal government. Since the passage of the Act, there has been a sharp increase in university patent licensing and a general increase in university support of research that is of direct interest to industry. Scholars are concerned that university licensing of research will involve restrictions on publication and other avenues of dissemination which may undermine the value of the research by reducing the volume of information flowing to potentially interested parties.

Universities in the U.S. National Innovation System

Growth in the stock of knowledge has been the most important factor behind the dramatic rise in living standards in the United States and other countries over the past one hundred years. Systematic efforts made by firms, universities, governments, and other organizations to increase the stock of knowledge are referred to as research and development (R&D). The purpose of this paper is to provide an overview of the entire system of R&D in the United States—or as it is sometimes called, the national innovation system. Special emphasis will be placed on basic research. This is the component of R&D that is most likely to be underprovided by the private sector and the one that figures most prominently in public policy toward science and technology. The report also emphasizes the role of universities which, in the United States, perform the lion's share of basic research.

The report provides a variety of basic statistical indicators of R&D effort and identifies recent trends in sources of R&D funding. The report also reviews classic arguments on the appropriate role of government in supporting R&D and the strengths and weaknesses of universities as performers of R&D. The U.S. national innovation system is compared with those in other major industrialized countries.

The Size and Nature of U.S. R&D

Total R&D

In the United States, estimates of expenditures made to increase knowledge are based on R&D surveys conducted by the National Science Foundation. The surveys are carried out following international guidelines set by the OECD. R&D is defined broadly as creative work undertaken in a systematic way to increase the stock of knowledge about humanity, culture, and society. (National Science Foundation 2002, p.4-10)

Figure 1 shows recent trends in U.S. R&D expressed per $1,000 of GDP. U.S. total R&D expenditures in 2002 were $276 billion, or 2.7 percent of GDP. The intensity of R&D has averaged 2.6 percent of GDP for each of the last two decades. This is down from a rate of 2.8 percent in the 1960s, but it is significantly higher than the rate of 2.3 percent averaged during the 1970s.

R&D by character of work

R&D expenditures are broken down into categories based on the immediacy of their intended application and their contribution to fundamental scientific knowledge. *Development* refers to research directed at "the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes." *Applied research* is aimed at meeting "a specific, recognized need" and includes investigations that have "specific commercial objectives with respect to products, processes, or services." *Basic research* is aimed at gaining a fundamental understanding of a subject without specific applications in mind. (National Science Foundation 2002, p.4-10)

It is inaccurate to think of basic research as being carried out without any regard for whether it will help solve practical social problems. The great majority of research expenditures at universities, for example, three-quarters of which are classified as basic, are oriented toward solving practical problems in health, agriculture, defense, and industrial technology. Among federal agencies that fund basic research, the National Science Foundation does support research based solely on its potential for advancing general scientific knowledge. But the National Institutes of Health, which account for a much larger share of federal basic research funding, rate proposals in large part on the basis of how likely the research is to address specific health problems. The Department of Defense, NASA, and the Department of Energy are known to choose projects on the basis of how well they fit into the practical missions of their programs. (Rosenberg and Nelson 1994)

Figure 1 provides a sense of the relative size of the various categories of R&D. Development expenditures are by far the most important component, averaging 60-65 percent of total R&D over the past two decades. Applied research is the second largest category, accounting for roughly 22 percent of total R&D. Basic research now accounts for 18 percent of total R&D, up from 13 percent from the late 1960s through the mid 1980s.

Importance of basic research in public policy

While basic research accounts for a relatively small share of total R&D, it figures prominently in the R&D budgets of governments and in debates about public policy toward science and technology. The benefits of product development and much applied research are likely to be well appropriated by the unit conducting the research. So incentives are strong to generate this type of research activity within private industry. The benefits of basic research, on the other hand, are long-term in nature, diffuse and difficult to predict. A basic research project may produce information that is useful to other organizations but not to the discoverer. Because of spillovers in basic research, it is difficult for the discoverer to appropriate a significant fraction of the ultimate commercial value of his findings.

The private sector will underinvest in R&D if new knowledge is difficult to keep proprietary. But it may be wrongheaded to try to address the problem of appropriability by simply strengthening property rights for the discoverer and fostering the creation of technological monopolies. Effective extension and development of basic research findings requires that the results be open and widely available to end users and researchers in other fields. Optimal policy involves public subsidy of basic research activity together with a system that promotes wide dissemination of research findings. (Noll 1998)

Who performs R&D?

Private industry performs over 90 percent of development and about 70 percent of applied research. As a result, industry accounts for almost three-quarters of total U.S. R&D (see

Figure 2). Basic research, on the other hand, is performed primarily in universities and colleges. Institutions of higher education now perform about 60 percent of all basic research. Industry performs 18 percent of basic research. Thirteen percent of basic research is done by nonprofit organizations, and 9 percent is carried out in federal government laboratories and agencies. The share of basic research performed in universities has risen over the postwar period from about one-third in the early 1950s to one-half by the early 1960s and then to around 60 percent by the early 1970s.

The high share of basic research performed in universities is in large part attributable to major decisions made by the U.S. federal government following WWII concerning government support of military and non-military research. Government officials and the general public were impressed by science and technology research efforts during the war (e.g., the Manhattan Project) and by the role that university scientists had played in those efforts. The political climate was ripe for Vannevar Bush when he argued in his *Science: The Endless Frontier* (1945) for continued large-scale public support of scientific research. What Bush called for, and what was later put into action, was a massive increase in federal funding of science and technology research with much of that research, especially the basic research, to be done at the nation's universities rather than in government laboratories. Most of the funds for military R&D went to industry for the development of missile systems and components. But some funding for military R&D did find its way to universities to support research in computers, electronics, and engineering. A second part of Bush's proposals called for increased funding of health research. From the beginning, the National Institutes of Health directed most of their funding to universities. A final part of the post-war R&D strategy of the country was to support basic research in its broadest sense. This objective eventually led to the establishment of the National Science Foundation which became a major funder of academic research. (Rosenberg and Nelson 1994)

A divison of labor: Advantages universities have in doing basic research

That almost all of the "D" in the nation's R&D is done in private industry, and that a majority of the "R" is done at universities, reflects an efficient and understandable division of labor. Development of products and processes is usually based on old science. This kind of research does not generally appeal to an academic, nor is it necessary that a development researcher be familiar with the latest scientific research. What is important in development is that researchers have a detailed understanding of user needs and existing technology. Many university professors are too far from the market or the factory floor to make good commercial judgements in areas of product or process development. (Rosenberg and Nelson 1994)

Private industry, on the other hand, is not well suited to doing basic research. Given the difficulty of appropriating commercial value from basic research, it is unrealistic to expect industry to carry out basic research without substantial public subsidy. Industry perspectives are also too narrow. The path of innovation from discovery in a basic research setting to specific commercial application is unpredictable and inherently "nonlinear". The ultimate application of knowledge may be so unrelated to the experiences of the original discoverer as to be hidden.

A defining feature of the U.S. national system of innovation is that most basic research, especially federally-funded basic research, is carried out in universities rather than in government laboratories (as in Europe) or in industry (as in Japan). Universities have several advantages over other organizations as performers of basic research:

The most important consequence of having research performed at universities is that it leads to the collocation of research and education. Arguments concerning basic complementarities between research and teaching were articulated in the early 19th century by Wilhelm von Humboldt. His ideas and values were influential in defining a model for the German university system, a model that was later adopted and extended by American universities.

Students assist with research and help transfer research findings to industry. One of the advantages of coupling teaching and research is that students can be used in the research process. Efficient research teams, especially in the life sciences and engineering, now routinely involve a faculty member who directs a research team comprised of postdocs, Ph.D. students, M.S. students, and even undergraduates. By being involved in research, students also become a conduit through which new research findings and technologically important knowledge is transferred to industry. This is especially important for the transmission of tacit components of new knowledge. (Feller 1999)

Research universities are good at training future researchers. In considering alternative ways of training future researchers, it is important for trainees to be involved in the research process. The mentor-apprentice relationship is still necessary, especially for the transmission of tacit knowledge and methodology. Universities have an important advantage over government or industry laboratories in that they can also provide a general curriculum of study and coursework. To prepare for a life of research, a trainee needs a broad array of theory and skill which is well provided by a university department (Clark 1995).

The academic merit system promotes rapid dissemination of research findings. Because of the complex and unpredictable nature of the path from discovery to eventual commerical application, it is important that basic research findings be open and widely disseminated. Through their publications and seminars, academics rapidly disseminate new ideas. Indeed, career rewards in academics depend more on success in disseminating new knowledge than in commercial application of that knowledge.

Academics can be entrepreneurial. The convention of funding academic posts for only nine months provides the academic researcher with an opportunity to engage in consulting or to assist with the start-up of new businesses. Full-time employees of national laboratories or research institutes do not have this flexibility and cannot be as entrepreneurial. This is especially true in European countries where strict employment protection laws make it difficult for a research professional to secure another research position once he has left one. (Mowery and Rosenberg 1993)

Academics can afford to take risks in research. Finally, the coupling of research and instruction provides a core level of income to the academic researcher that enables him to take risks in research (Feller 1999).

Who funds R&D?

Total R&D

Total R&D is funded primarily by private industry. This is not surprising given that the majority of R&D is for development. In 2002, industry funded 66 percent of total R&D. The federal government now funds 28 percent of R&D. The remaining 6 percent is divided between universities and colleges, nonprofit organizations, and nonfederal governments.

There have been major shifts in the sources of R&D funding over the post-war period. As noted earlier, there was a massive buildup of federal R&D support beginning in WWII and continuing through the mid 1960s. Federal funding of R&D went from .75 percent of GDP in 1953 to a high of 1.98 percent of GDP in 1964. Defense and space-related R&D played major roles in this buildup. Federal funding began to fall as a percent of GDP in the 1960s—first in defense-related spending beginning in the early 1960s, and then in space-related spending beginning in the late 1960s. Except for a brief buildup during the Reagan years, federal R&D support has fallen continuously from its high in 1964 to .76 percent of GDP in 2002. Federal funding accounted for 67 percent of total R&D in the mid 1960s but is now down to around 28 percent.

There has been a steady increase in industry support for R&D since the end of WWII. Industry funding of R&D has risen from 0.60 percent of GDP in 1953 to 1.75 percent of GDP in 2002. Industry accounted for only 44 percent of total R&D in 1953, but now accounts for about two-thirds of the total.

Basic R&D

Shifts in the funding of basic R&D have been notable although not as dramatic as the shifts in the funding of development. Funding for basic R&D jumped after the war, especially the contribution of the federal government. Increases in federal support drove total funding for basic R&D from 0.12 percent of GDP in 1953 to 0.39 percent by the late 1960s. Funding for basic R&D fell during the 1970s to a low of 0.31 percent by 1979. Funding then began to recover in the 1980s, and it has averaged 0.44 percent of GDP since 1991.

There have been significant changes in the sources of funding for basic R&D (see Figure 3). The share of funding provided by the federal government rose after the war to around 70 percent by the mid 1960s. The federal share held steady at about 70 percent until the early 1980s. The share then fell to around 60 percent by the late 1980s. Since 1991, the federal share of basic R&D funding has averaged 57 percent.

The share of basic R&D funded by private industry increased from around 15 percent in the 1970s to around 25 percent by the mid 1990s Since 1998, however, industry's share has fallen to around 19 percent. The share of funding accounted for by universities and colleges has increased steadily over the past four decades from an average of 3.4 percent in the 1960s to 9.1 percent from 1993-2002.

The federal government continues to fund most of the nation's basic research, accounting for 59 percent of total funding in 2002. Including FFRDCs, universities and colleges perform two-thirds of all federally-funded basic research. Only 15 percent of federally-supported basic R&D is carried out in government laboratories.

Historical origins of the American research university

Founding of American colleges and universities

The greatest rate of increase in the number of colleges and universities operating in the United States occurred during the last four decades of the 19th century. The Morrill Act of 1862 established the land-grant state colleges. A large number of public institutions of higher education were already in existence at the time of the Morrill Act. But this legislation, together with the Hatch Act of 1887, was important in creating state institutions that would not only educate large numbers of Americans but would play an influential role in the development of research and technology programs with practical applications to industry.

Almost five times as many private institutions as public institutions were founded over the period 1860-1899. It was in the late 19th century that wealthy American industrialists endowed many of the great private research universities. The creation of these private universities was aided by the fact that the U.S. government made donations to institutional endowments deductible under the federal income tax.

Relatively few institutions of higher education were founded after the turn of the century, and those that were have not tended to be as prestigous. Among the 35 private institutions in the top 50 universities in the 1999 rankings of U.S. News and World Report, only one was founded after 1900. Of the top 35 liberal arts colleges, only two were founded in the 20th century. Goldin and Katz (1999) attribute this lack of entry into the higher education industry to financial barriers associated with the large scale and scope necessary to compete.

The formative years: 1890-1920

Features that define the U.S. system of higher education include large average institutional size, the existence of small liberal arts colleges along side large research universities, a large share of enrollment in public institutions, and professional schools embedded within universities. It was in the first several decades after 1890 that these features took shape. (Goldin and Katz 1999)

Most fundamental as a factor driving the evolution of the American university system was the increasing application of scientific knowledge in industry. Principles of chemistry and physics became the foundation for commerical success in the manufacture of steel, rubber, chemicals, petroleum, and electricity. Science was replacing craft in production. Industry came to call on universities both to create new knowledge in these fields and to train the chemists, engineers, and technical workers they would need to hire.

As the stock of scientific knowledge grew and the process of research became more complex, it was inevitable that scientific disciplines would become more specialized. This, in turn, forced institutions of higher education to expand their scale and scope. During the early to mid 19th century, institutions were staffed by a handful of faculty whose proficiency may have been limited to philosophy, history, religion, and the ancient languages. To meet the new demands of industry and society, universities had to employ large numbers of specialized faculty with teaching and research expertise that covered an increasing variety of scientific fields.

There was a general increase in scale throughout the higher education industry during the early 20th century. But increases in scale were especially significant in public universities. The ratio of the median number of students in public and private institutions was 1.89 in 1897, but 3.41 in 1924 and 4.09 in 1934. The share of students in public institutions increased from 22 percent in 1897 to around 50 percent by 1940.

On both a per capita and per student basis, state funding of public universities was insignificant before 1890 but then increased rapidly as science became important to local industry. Public-sector institutions gained a competitive advantage from the research support provided by state governments and by being able to offer students lower tuition. Economies realized from this larger scale were self-reinforcing and served to further strengthen the competitive advantage of public universities. The general scale of colleges and universities continued to increase after WWII, but at a more similar pace across public and private institutions.

Another important structural feature of American universities that took shape during the early 20th century was the university professional program. At the turn of the century, 48 percent of students training to be doctors, lawyers, dentists, and pharmacists attended professional schools that were not formally associated with any institution of higher education. Many of these professional schools did not require a college degree. By 1934, however, only 19 percent of professional students were attending professional schools. Health-care and legal professionals increasingly needed scientific and technical training. Schools that provided professional certification were expected to have research facilities and to provide a rigorous scientific curriculum. Informal apprenticeship programs were replaced by formal school-based programs.

By the 1920s, the U.S. system of research universities was largely in place. By 1940, American universities were regarded as equal to or better than the best universities in Europe. American universities were unique in combining a multitude of functions. Many offered high quality undergraduate programs that rivaled the classical British colleges. American graduate and professional programs came to surpass the French ecoles for the quality of their technical training. With their strong research programs, American universities also began to outperform the famous German research universities. The dominance of the American university in the marketplace for higher education lends testimony to the idea that a university is more than simply a collection of higher education services brought under one roof. It is an organizational innovation that exploits the economic complementarities that exist between teaching and research (Goldin and Katz 1999).

Early importance of state funding

The nature of the curriculum and research in American universities that developed in the early 20th century was heavily influenced by the sources of university funding. Prior to WWII, the federal government contributed very little to the incomes of universities. The many public institutions in the nation were controlled and funded by the states rather than the central government. The politics of state funding meant that the leaders of these universities became very sensitive to the needs of local industry and to the priorities of state legislators.

State funding of public universities was meager for many years after these institutions were founded but then jumped in the late 19th century as science became critical to the success of local industry. In exchange for this financial support, public universities were expected to develop a curriculum that would provide vocational skills important for local industry. States also subsidized university research that was of practical significance to local industry. Wisconsin subsidized work related to the dairy industry, Iowa to the corn industry, Colorado and many western states to mining, and Oklahoma and Texas to oil exploration and refining (Goldin and Katz 1999).

During this period, American universities acquired a reputation for "hands-on problem-solving," something that was lacking in British and European institutions. American universities assumed a responsibility for teaching and doing research not only in such applied areas as agriculture and mining but also in commercial subjects such as accounting, finance, and management. American universities were also the first to institutionalize many of the new fields of engineering, including chemical engineering, electrical engineering, and aeronautical engineering.

Before 1940, little of the research being done at U.S. universities was contributing to the fundamentals of science. But American universities were highly successful at producing engineers and other technically-trained workers who transferred valuable scientific knowledge to industry. The U.S. university system at the turn of the century helped to diffuse scientific knowledge and was instrumental in allowing the United States to catch up with international standards of technology.

Federal funding after WWII

The federal government contributed very little to the funding of American universities before WWII. Following the war, the federal government initiated a massive campaign of funding research at universities. Federal programs also increased financial aid to students, starting with the GI bill and then later in the form of subsidized student loans, Pell grants, and work-study assistance. Federal funds also made it possible for universities to purchase expensive scientific equipment. Between 1940 and 1950, the contribution of the federal government to the incomes of universities increased from $39 million to $524 million.

The federal government became the universities' principal source of research funding. The nature of university research was totally transformed by this new source of funding. The direction of university research shifted away from research intended for local industry application to more basic scientific research, with applications to national goals in defense and health care. As the federal government began to displace state governments as decision makers in the university innovation system, there was some weakening of the ties between university research insitutions and private industry. (Mowery and Rosenberg 1993)

Recent trends in the funding of academic R&D

The intensity of support for academic R&D, as measured by funding as a percent of GDP, has increased in all funding sectors throughout the last three decades (see Figure 4). Total support for academic R&D has increased from an average of $2.16 per $1,000 of GDP over the period 1972-1981 to $3.04 per $1,000 of GDP over the period 1992-2001. The intensity of support by the federal government has risen as a percent of GDP but accounts for a declining share of total support for academic R&D. The share of academic R&D supported by the federal government has fallen from 68 percent in the 1970s to 59 percent. Academic R&D funded by the universities and colleges themselves has increased from an average of $0.28 per $1,000 of GDP from 1972-1981 to $0.58 per $1,000 GDP over the period 1992-2001. The share of total academic R&D funded by universities is now around 20 percent, up from 13 percent in the 1970s.

According to official figures, state and local governments account for only 8 percent of the funding of academic R&D, about the same share contributed by private industry. It is important to note, however, that the figures for S&L government funding only include funds directly targeted to academic R&D activities. They do not include general-purpose state and local appropriations that academic institutions use to fund separately budgeted research or to cover unreimbursed indirect costs. In data for other countries, totals include the research component of general university fund block grants provided by government. These figures often include separately budgeted research and research undertaken as a part of university departmental R&D activities. Much state funding in the U.S. does support departmental research, but detailed accounting breakdowns are not maintained by universities. U.S. totals for academic R&D effort are certainly understated relative to other countries. (Science and Engineering Indicators 2004, p.4-49)

Within the category of federal funding of academic R&D, there has been a significant shift toward health-related research (see Figure 5). Funding obligations from the National Institutes of Health have increased from around $0.60 per $1,000 of GDP in the early 1970s to an average of $1.15 from 2000-2002. Funding obligations from the National Science Foundation fell during the 1970s but have since held steady at around $0.25 per $1,000 of GDP. Support for academic R&D by the Department of Defense has fluctuated from a low of $0.14 per $1,000 of GDP in the mid 1970s to a high of $0.25 in the mid 1980s and early 1990s.

International comparisons of R&D effort and output

Total R&D effort

Because of the absolute size of the U.S. economy and the relatively high intensity of its effort, the United States spends much more than any other country on R&D (see Figure 6). Over the ten-year period 1991-2000, the U.S. performed 43 percent of the total R&D in OECD countries. Japan was a distant second with an 18 percent share of OECD R&D activity. When expressed as a percent of national GDP, the U.S. is also well above average in R&D intensity (see Table 1). The U.S. devotes 2.71 percent of its GDP to R&D, as compared with an OECD average of 2.24 percent. Israel rates highest in R&D intensity, spending 4.43 percent of its GDP on R&D, much of it on defense. Other countries with very high R&D intensity include Sweden (3.78 percent), Finland (3.37 percent), and Japan (2.98 percent).

Comparing output and productivity in basic research

Incomparabilities in the classification of R&D data make it difficult to compare R&D effort by character of work (ex—just basic research). Output of basic research (as opposed to expenditures) can be measured and compared across countries by counting numbers of science and engineering articles published in academic journals (see Figure 7). The United States leads all countries by a wide margin, accounting for 38 percent of all articles published by OECD authors over the period 1997-2000. The U.S. share of S&E articles is five percentage points less than its share of total R&D. This is an indication of the relatively important role played by industry and product development in overall U.S. R&D. Japan exhibits an even stronger tendency to spend on development rather than basic research. Japan accounts for 18 percent of total R&D in OECD countries but only 11 percent of S&E articles. The U.K., on the other hand, is more oriented to basic research. Its share of articles is 9 percent while its share of total R&D is only 4 percent.

Based on international comparisons of the field distribution of scientific articles, the U.S. is seen to place relatively heavy emphasis in its academic research on medical and health science, psychology, social science, and the professional fields (see Table 2). Receiving less attention in U.S. basic research are chemistry, physics, and engineering. These tendencies are especially pronounced when comparing the U.S. and Japan.

One measure of the productivity and quality of a country's academic research is the citation frequency of its articles after adjusting for its share of published articles (see Figure 7). By this measure, the United States ranks 2nd overall, 1st in clinical medicine and social science, and 2nd in biomedical research. Switzerland ranks 1st overall and 1st in biomedical research, biology, physics, and engineering and technology. Because of a lack of emphasis on basic research, Japan does not rank in the top ten in any of the scientific fields. It should be noted, however, that measures of relative citation frequency are known to be biased in favor of English-speaking countries.

International differences in the way basic research is performed

This section provides a brief overview of the systems for performing basic research in five major industrialized nations: the United States, Germany, France, Britain, and Japan.

The American system

Coupling of research and graduate education: Compared with other countries, a relatively large percentage of U.S. basic research is performed at universities by faculty who are also actively involved in education, especially graduate education. In other countries, few universities rank among the best research institutions, and many of the best research scholars in science and engineering do not teach (Cohen and Noll 1992).

Many of the complementarities between research and teaching have already been noted. The coupling of research and graduate education has helped the U.S. to develop an effective system of technology diffusion through their students and to build the premier system of graduate instruction in the world. Unique among U.S. graduate schools is that students are required to complete a broad curriculum of rigorous coursework. Students are not simply research students. They are expected to master a broad range of skills which will help prepare them for a long research career.

To Donald Kennedy, the most significant implication of the choice of the U.S. government to support basic science through the universities is that “the nation’s research trainees are being developed alongside the best scientists.” To this feature of the U.S. system “our most thoughtful European colleagues usually attribute our special success.” (Kennedy 1986, p.264)

Decentralized funding: Sources of funding for U.S. basic research are relatively diverse and decentralized. Although much of the funding for academic R&D comes from the federal government, this funding involves a number of federal departments and agencies with separate missions and goals. Funding decisions in some agencies, such as the NSF, are based largely on peer review. Distribution of government research funds in European countries is more centralized and often determined by formulas and rigid bureaucratic procedures. Private support for universities, through individual donations and grants from companies and foundations, is almost unheard of outside of the United States. State governments also play an important role in funding U.S. university research, to a much greater degree than is indicated in official statistics.

Diversity in funding has enabled U.S. universities to pursue multiple lines of research without being stifled by prevailing paradigms. Paths of innovation in basic research are highly uncertain and impossible to predict. The best strategy is to pursue several lines of research simultaneously and to then eliminate those that are found to produce bad results. Central governments tend to emphasize large projects with major research centers that are politically difficult to shut down (Cohen and Noll 1992). Diversity in funding has allowed U.S. university researchers to choose lines of research based more on scientific merit, with relatively less consideration for how well the research fits with political agendas of elected officials or the preconceptions of industry sponsors. (Feller 1999)

Competition among universities: The U.S. university system is highly competitive, involving a large number of heterogenous institutions, both public and private. The competitive nature of the system promotes efficiency in the production of basic research, in the employment of scientists and faculty, and in the training of future scientists.

University competition for research funds is intense, and many institutions play an important role in performing the nation's basic research. The top ten institutions in the country account for approximately 15 percent of total academic R&D, and the top 50 institutions account for only a little more than half. Indeed, the distribution of academic R&D is becoming more dispersed over time (Feller 1999). Because of competition for research funding, universities must manage costs well and be willing to adjust research portfolios to accommodate shifts in demand. In the decentralized U.S. system, universities are also able to specialize in market niches.

Competition among universities also helps to create a competitive market for scientists and faculty. This raises compensation and increases the mobility of researchers. Because the terms of compensation are favorable and there are so many employment opportunities in the country, the U.S. has been a magnet for migrating international scientists.

According to Clark (1995), competition among universities is what produced unparalleled excellence in U.S. graduate programs. Intense competition for research funds, faculty, and students, together with controls through professional associations, forced graduate programs to develop the high quality and rigorous curriculum that U.S. graduate programs are famous for. In comparison to other advanced countries, American education is weak at the elementary and secondary levels, strong at the tertiary level, and without peer at the graduate level. The most plausible explanation for the special success of U.S. graduate schools "centers on the initiative exercised by a plurality of institutions in a uniquely competitive arena. Processes of competition that never developed in American elementary and secondary education, nor to anywhere in the same degree in higher education elsewhere, operated intensively in American higher education, preeminently to the advantage of the most advanced tier" (Clark 1995, p.117).

Scholars are reluctant to declare the U.S. system of basic research, with its heavy reliance on universities, as the premier and most efficient research system in the world. But this conclusion could certainly be supported by various indicators of basic research performance, such as the share of postwar Nobel Prizes won for research performed in U.S. laboratories and citation analysis of scientific papers.

The German system

It was Germany that pioneered the concept of the research university during the 19th century, and research universities were instrumental in making Germany a world leader in basic science by the early 20th century. The German innovation system was then severely weakened during the Nazi period. A further decline in universities has occurred since the mid 1970s as university funding has not kept pace with student enrollments. Universities now play a relatively minor role in performing the nation's research.

German government and industry together make a serious commitment to research. But this research is now carried out largely in national laboratories and research institutes that have only weak associations with universities. Much of the research function in universities has moved offsite to external institutes. These institutes are increasingly disconnected with students, and they are having a hard time competing with other institutes for national research funds. German universities now primarily serve the function of providing mass education, with faculty being assigned heavy loads of introductory teaching.

The German system does not strongly support advanced training in universities. Doctoral students work closely with a professor-supervisor and may spend 3-5 years assisting in research. Coursework is negligible, however. Students are essentially being trained to fill specific occupational niches. Research institutes that are connected with universities may also be involved in the training of students. But again these students do not receive a broad education in general theory and research methods. In general, the German system of graduate education suffers from a thin curriculum of study. (Clark 1995)

The German innovation system fell into oblivion during the 1930s and 1940s and has never regained its former level of excellence. This is a principal reason for why German industry today has a comparative advantage in only those areas with a long tradition of technological strength. German industry has failed to excel in the new areas of technology such as computers, microelectronics, and biotechnology. One of the weakest elements of the German system is higher education. There is a particular need for a closer integration of research and education. (Keck 1993)

The French system

France offers the clearest example of a research system that is controlled by central government and in which there is virtually a complete separation of research and education (Clark 1995). The French system consists of three largely independent sectors: (1) the National Center for Scientific Research (CNRS)—a research bureaucracy sponsored by national ministries and organized into eight scientific departments which operate more than 1,200 laboratories throughout the country; (2) the Grandes Ecoles which are responsible for the training of elite students in engineering and other technical and professional areas; and (3) the universities whose principal function is to provide for mass education.

Government-supported research is carried out in two sectors: the prestigous and highly centralized CNRS and the less prestigous university system that is also responsible for the doctoral training. CNRS laboratories dominate French research, accounting for half of all scientists and engineers engaged in basic research. Only a handful of universities participate broadly in research, and this is usually done in separate institutions that are disconnected from teaching (Noll 1998). Most of the nation's research has been outside of the univesity system for more than half a century. The French government has recently tried to encourage CNRS-university linkages, placing many laboratories at universities so that faculty and students can participate. These laboratories remain under the control of the CNRS, however, and the CNRS determines which universities to associate with (Clark 1995).

France has a dual education system that dates back to the early 19th century. Advanced training takes place in the Grandes Ecoles. The ecoles admit a small number of carefully selected students and receive generous government support. Students attending the ecoles receive training in engineering and other professional and technical areas with the clear intention of preparing students for a future career in public ministry or in the management of powerful French firms. Students do not receive training in fundamental scientific methods. Faculty do no research. (Chesnais 1993)

The French university system was abolished during the French revolution and reestablished by Napoleon with a purely teaching function. The universities are poorly funded and are considered inferior. The universities are charged with performing doctoral training. Doctoral training involves very little formal coursework. Students must be sponsored by a professor who then prepares the student for entry into national laboratories. Financial support for doctoral programs is adequate in the sciences but seriously deficient in other academic disciplines.

The British system

Britain was the world's undisputed technological leader from the mid 18th to late 19th century. At that point, Britain began to suffer a steady decline in industrial standing to the point where, outside of a few niche areas, she is no longer considered a technological leader. Britain lacks the culture and institutions necessary to compete in modern manufacturing. Success in such industries as chemicals, automobiles, and electronics has required a commitment to excellence in science and industrial management which Britain never developed. Britain has not made innovation a priority. Britain suffers from chronic underfunding of education and training, weak government support for nondefense R&D, a financial system that places heavy emphasis on short-term gain, and a culture that does not value technological expertise. (Walker 1993)

The British university system is characterized by small residential colleges where undergraduates work closely with a professor-supervisor and receive intense training in a specialized area. Britain never tried to develop German-style research universities. Departments have been kept small. This lack of size has made it difficult for departments to hire specialists, to cover broad areas of curriculum, and to compete for research grants.

Since the mid 1960s, the university system has become nationalized and is now subordinate to the education department of the national government. Salaries and pay scales are standardized so that departments cannot compete for faculty. The control of higher education has moved from a policy style of "bottom up, hands off" to "top down, hands on." Undergraduate quality has been maintained through internal controls. But the national government has reduced its support for students (from 80% to 40%) and will only pay for quality. (Clark 1995)

Most graduate programs in Britain are too small to offer a broad range of courses. In training graduates, Britain still follows an apprenticeship model in which students work closely with a single professor. Training is not standardized, and it does not involve heavy coursework. This highly personalized system of graduate training is costly and so has frequently become the victim of budget cuts. The British university system de-emphasizes graduate education and remains focused on producing excellence in undergraduate education for an elite few.

The Japanese system

Japan devotes a relatively high percentage of its GDP to R&D—about 33 percent more than what is average for OECD countries. An unusually large share of this spending, however, is for development and applied research. Funding for basic research is modest. What basic research is done is performed in private industry, with a heavy focus on engineering.

Japan's universities are specialized in the production of engineers. The pride of Japan's system of graduate education is its master's degree in engineering. There is little financial support for education in the humanities and social sciences. Engineering is also considered to be the best training for leadership in industry. There is no industry demand for MBAs. Degree statistics tell the story. With a population only half the size of the U.S., Japan graduates as many engineers with bachelor's degrees. But Japan's output of doctorate degrees is only one-tenth that of the U.S.

In the Japanese system, universities are not called upon to do basic research. The mission of Japan's universities is to select talent and to train students for careers in applied fields such as engineering and medicine. Programs for graduate education in basic science and research-based doctoral training are weak. The responsibility for research activity and research training rests primarily with private industry. Because of its narrow perspective and a tendency to keep new knowledge proprietary, however, private industry may not be as effective as academia in performing basic research. In advanced training of future researchers, industry cannot match university departments for breadth of curriculum and coursework. (Clark 1995)

According to Odagiri and Goto (1993), the Japanese government is aware that the country needs to do more basic research. The country has long ago caught up with best practices and now needs to create new technology of its own. As a recognized peer of the most advanced and industrialized countries in the world, Japan also sees itself as having a responsibility for contributing to the world's production of international public goods, including scientific knowledge. Japan's basic research expenditures have increased over the past two decades, but more so in industry than in academia. It is unclear whether private industry can be relied upon to lead the country to a new level of basic research when its abilities to carry out research and research training are questionable and when there is little private incentive to undertake basic research.

Recent changes in the U.S. national innovation system

Shifts in the funding of R&D

The sources of funding U.S. R&D have shifted substantially over the past several decades. The federal government has sharply reduced its R&D spending, especially the part related to national defense. From the mid 1980s through the early part of this century, federal R&D spending has fallen from 1.24 percent of GDP to 0.72 percent. More than 80 percent of this decline can be accounted for by cuts in defense-related spending. Total R&D effort in the country has remained unchanged, however, because of offsets in industry R&D. Since the mid 1980s, industry funding of R&D has increased from 1.38 percent of GDP to 1.83 percent. With these divergent trends, the share of total R&D funded by the federal government has fallen from 46 percent to 27 percent, while industry's share has increased from 51 percent to 68 percent.

The great majority of federal defense-related R&D has been in areas of development and applied research, such as weapons testing. This kind of research provides few civilian benefits. In general, technological spillovers from defense to civilian applications are thought to have been less signficant in recent decades than they were in the 1950s and early 1960s. During the earlier period, there was more overlap in public and private research requirements, especially in aerospace and electronics (Mowery 1998). It is likely then that the shifts in the sources of funding R&D that have taken place over the last twenty years have served to raise the nation's overall resource commitment to generating knowledge that is useful for the production of civilian goods.

All of the decline in federal R&D spending has occurred in categories related to development and applied research. Federal support of basic research has actually increased, from 0.23 percent of GDP in the mid 1980s to around 0.27 percent in the early twenty-first century. Total basic research in the country is also up, from 0.37 percent to 0.46 percent of GDP. The share of basic R&D funded by the federal government has fallen from 63 percent to 58 percent. This has been offset by rising shares from universities and nonprofit organizations. Industry's share of basic R&D rose from 21 percent in the mid 1980s to 26 percent in 1991, but it has since fallen to around 19 percent.

Support for academic R&D has increased from 0.24 percent of GDP to 0.31 percent, with all funding sectors contributing to the increase. The share of academic R&D funded by the federal government has fallen from 62 percent to 58 percent. This has been offset by rising shares from institutional sources (from 17 percent to 20 percent) and private industry (from 6 percent to 7 percent).

Changes in the way industry performs R&D

Private industry is changing the way it performs research. Because of disappointing returns to internal R&D and changes in federal antitrust policy, many firms have decided to "externalize" some of their R&D operations. Through research consortia, collaborations with universities, and strategic alliances with other firms, more firms are choosing to conduct R&D outside of their own organizations. (Mowery 1998)

Research activity is also becoming "internationalized". R&D that is funded by U.S. industry but performed offshore has grown only modestly. But there has been a significant increase in the fraction of industrial R&D performed in the U.S. and funded from foreign sources. (Mowery 1998)

Commercialization of university research

Through domestic legislation and greater emphasis in international trade negotiations, the U.S. has made a serious effort over the past twenty-five years to strengthen intellectual property protection. Most important for universities was the Bayh-Dole Act of 1980 which allowed federal agencies to grant licenses to small businesses and nonprofit organizations, including universities, for patents based on research funded by the federal government. Since the passage of the Act, there has been a sharp increase in university patent licensing and in the number of university offices of technology transfer. There has also been a general increase in university support of research that is of direct interest to industry.

The logic behind the Bayh-Dole Act follows the “linear model” of innovation: intellectual property protection will enable university researchers to realize a commercial return on their investments and this will serve to accelerate commercial innovation. It is assumed that parties for whom the research will have commercial value can be well identified and brought into the licensing process. This kind of public policy toward research is very different from what is recommended by economic theory. To optimally invest in and develop new knowledge, research should be publically funded and the findings should then be liberally disclosed and disemminated. Scholars are concerned that university licensing of research will involve restrictions on publication and other avenues of disemmination that will ultimately undermine the value of the research by reducing the volume of information flowing to potentially interested parties. The U.S. has been more aggressive than other countries in trying to extend intellectual property protection to the results of publically-funded research. (Mowery 1998)

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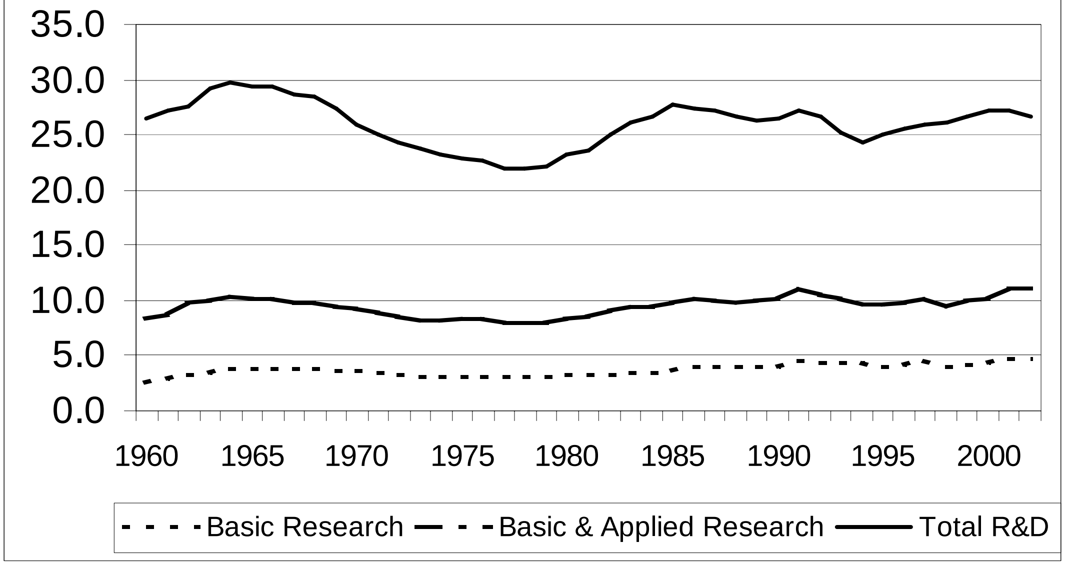

Figure 1: U.S. R&D Intensity by Character of Work

(Expenditures per $1,000 of GDP)

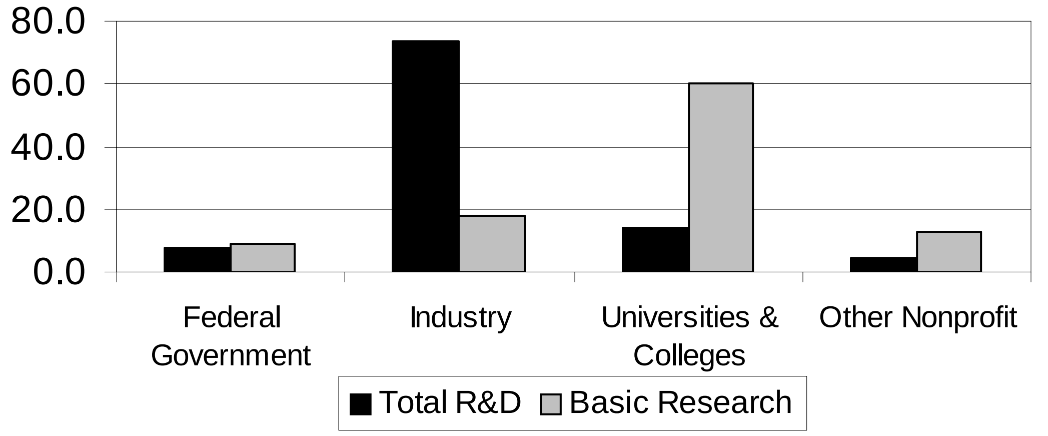

Figure 2: Who Performs U.S. R&D?

(percent of total, data from 1998-2002)

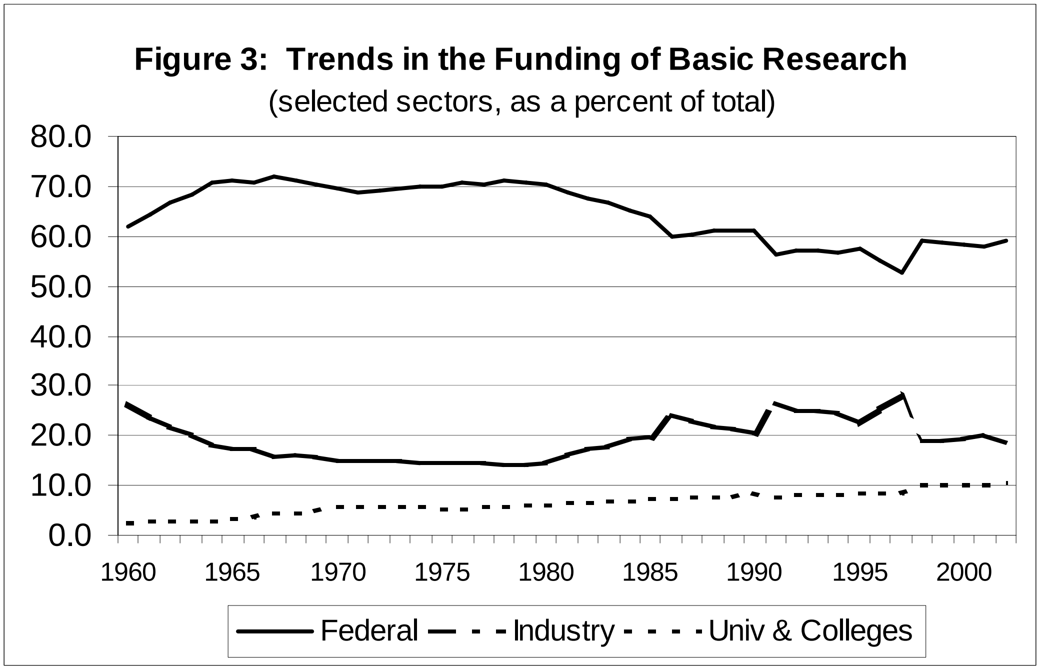
Figure 3: Trends in the Funding of Basic Research

(selected sectors, as a percent of total)

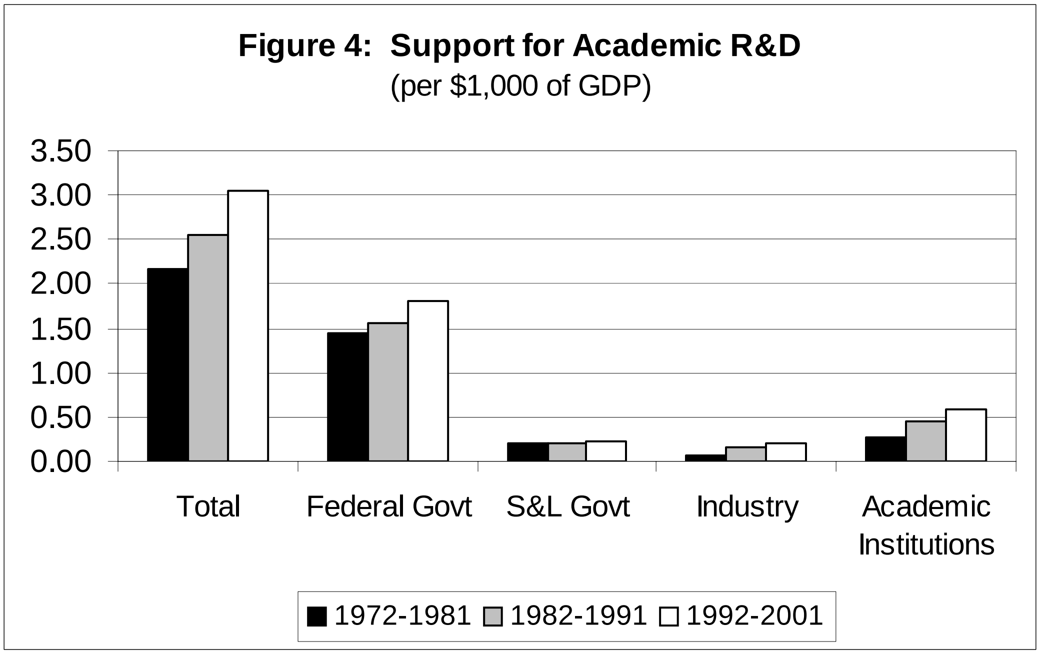
Figure 4: Support for Academic R&D

(per $1,000 of GDP)

Figure 5: Federal Funding of Academic R&D by Agency

(Obligations per $1,000 of GDP)

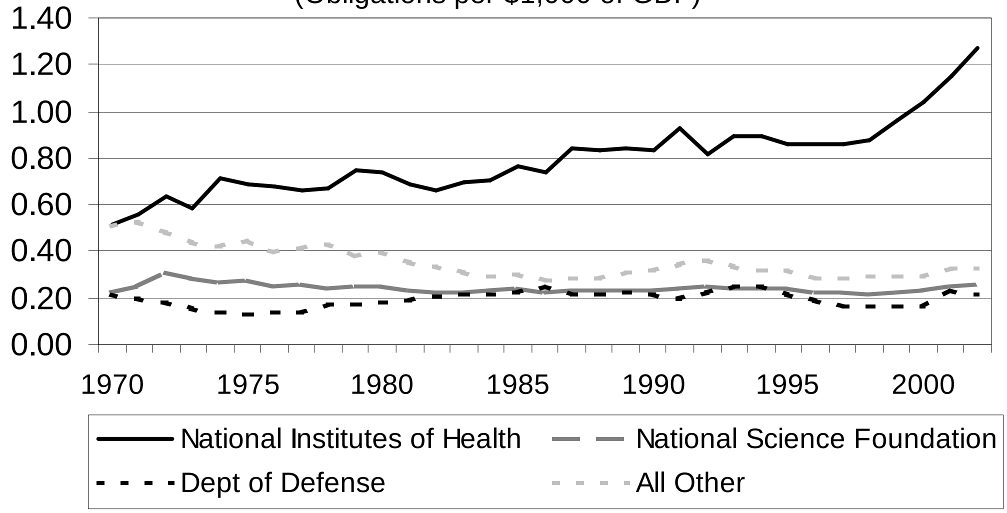

Figure 6: National Shares of R&D Spending, 1991-2000

(percent of total OECD R&D spending)

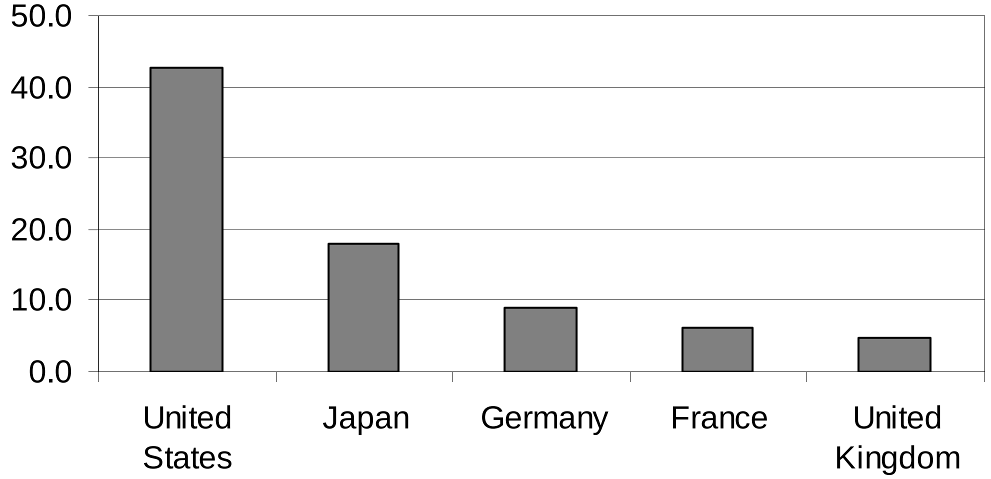

Figure 7: National Shares of S&E Articles, 1997-2001

(percent of total OECD articles)

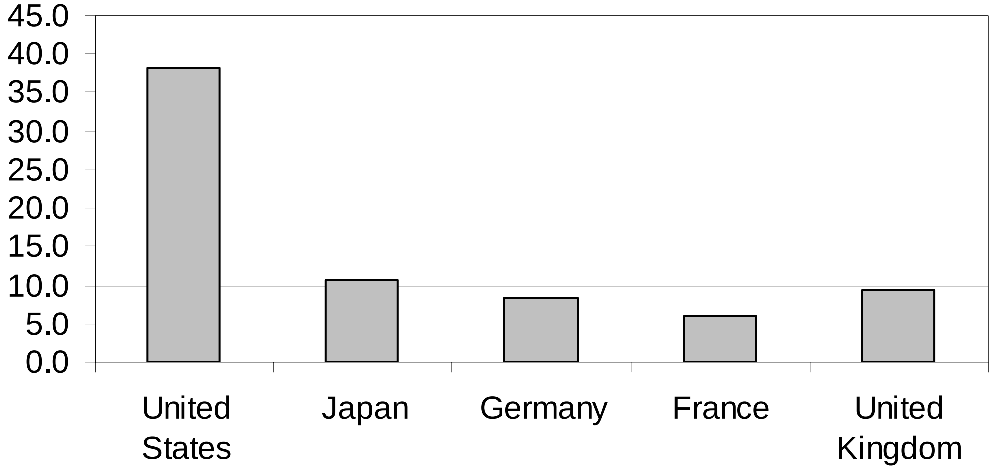

Table 1: International Comparisons of R&D Intensity

(Total R&D expenditures as a percent of GDP)

Israel (2001)	4.43	France (2001)	2.20
Sweden (1999)	3.78	Singapore (2001)	2.11
Finland (2000)	3.37	Taiwan (2000)	2.05
Japan (2000)	2.98	Canada (2001)	1.94
United States (2001)	2.71	United Kingdom (2000)	1.85
South Korea (2000)	2.65	Russian Federation (2001)	1.16
Switzerland (2000)	2.64	Italy (2000)	1.07
Germany (2001)	2.53	China (2000)	1.00

Total OECD (2000)	2.24

Source: Science and Engineering Indicators--2004, Table 4-17.

Table 2: Country Portfolio of S&E Articles by Field, 2001

(percent of country's total articles)

	Clinical medicine	Biomedical research	Biology	Chemistry	Physics	Engineering and technology	Social sciences	Other
United States	31.7	16.9	6.2	7.1	8.7	6.9	3.9	18.6
Japan	28.7	14.0	6.1	14.9	19.1	11.6	0.5	5.1
United Kingdom	32.8	14.2	6.2	8.5	9.0	7.4	3.0	18.9
Germany	30.9	14.1	5.2	12.7	16.3	8.5	2.0	10.3
France	27.1	15.2	5.7	12.9	16.1	9.0	0.9	13.1
All OECD Countries	30.7	15.0	6.8	10.3	11.9	8.2	2.6	14.5

Note: Fields grouped in "Other" are earth and space sciences, mathematics, psychology, health sciences, and professional fields.

Source: Science and Engineering Indicators--2004, Appendix Table 5-38.

Table 3: Country Rankings of the Relative Citation Frequency of S&E Articles, 2001

(Top ten countries as ranked by relative citation frequency)

All fields	Clinical medicine	Biomedical research	Biology
Switzerland	United States	Switzerland	Switzerland
United States	Switzerland	United States	Netherlands
Netherlands	Canada	Israel	Sweden
Denmark	Netherlands	United Kingdom	United Kingdom
Sweden	Finland	Germany	Denmark
United Kingdom	Ireland	Netherlands	Hong Kong
Finland	United Kingdom	Canada	Austria
Canada	Belgium	Austria	Estonia
Belgium	Sweden	Singapore	France
Germany	Denmark	Finland	Finland

Chemistry	Physics	Engineering & technology	Social sciences
Netherlands	Switzerland	Switzerland	United States
Switzerland	Denmark	Denmark	Singapore
Denmark	United States	Netherlands	Sweden
United States	New Zealand	Slovenia	Belgium
Israel	Netherlands	Austria	Denmark
Sweden	Austria	Germany	Hong Kong
Canada	Germany	United States	South Korea
Hong Kong	Israel	Ireland	Switzerland
United Kingdom	United Kingdom	Sweden	United Kingdom
Ireland	Ireland	France	New Zealand

Note: Rankings are based on a "relative citation index" which is a country's share of cited literature adjusted for its share of published literature. A country's citation of its own literature is excluded.

Source: Science and Engineering Indicators--2004, Appendix Table 5-50.