CBO MEMORANDUM

CURRENT INVESTMENTS IN INNOVATION
IN THE
INFORMATION TECHNOLOGY SECTOR:
STATISTICAL BACKGROUND

April 1999

CONGRESSIONAL BUDGET OFFICE
SECOND AND D STREETS, S.W.
WASHINGTON, D.C. 20515

NOTE

Numbers in the text and tables of this memorandum may not add up to totals because of rounding.

The President's budget for fiscal year 2000 includes a proposal to increase federal spending on research and development (R&D) of computer and data communications by $366 million. That proposal, called Information Technology for the Twenty-First Century, or IT^2, coincides with a significant upswing in private investment in such R&D. The outpouring of private funds raises the question of how much the IT^2 initiative can contribute to the nation's overall technology development effort.

The House Committee on Science has asked the Congressional Budget Office (CBO) to conduct two analyses of the IT^2 initiative: a statistical analysis of baseline spending in the technology areas that would be funded by the initiative and a policy analysis of the overlap between federal and private efforts in the information technology sector. This CBO memorandum responds to the first request. It provides background statistics about current private and public spending on R&D in the technology areas funded by the initiative. A later CBO analysis will address the substantive policy issues. In keeping with CBO's mandate to provide objective, impartial analysis, this memorandum makes no recommendations.

Philip Webre of CBO's Natural Resources and Commerce Division wrote the memorandum under the supervision of Jan Paul Acton and David Moore. Keith Mattrick provided research assistance and prepared the figures. Sean O'Keefe provided useful comments. Sherry Snyder and Chris Spoor edited the memorandum, and Angela Z. McCollough prepared it for publication. Laurie Brown prepared the electronic versions for CBO's World Wide Web site (www.cbo.gov).

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INTRODUCTION

The President's Information Technology Advisory Committee has proposed a five-year federal initiative that would double the current federal funding of roughly $1.5 billion for developing computer and data communications technology. Following the committee's general recommendations, the President's budget submission requests $366 million in new funds for fiscal year 2000 to stimulate innovation in that area. The Administration's proposal, called Information Technology for the Twenty-First Century, or IT^2, would distribute those funds among several agencies, with the National Science Foundation receiving the largest share.

This Congressional Budget Office (CBO) memorandum provides background statistics on the current level of spending by federal, industrial, and academic organizations on research and development in the computer and data communications—or information technology (IT)—sector. It also provides statistics on the human resources available to that sector. A later CBO analysis will explore in depth the substantive policy issues raised by the IT^2 initiative.

The statistics and data in this memorandum provide a snapshot of the nation's innovation capabilities in the IT area. Four actors dominate that sector: federal agencies, private companies, and venture capitalists, which are the main sources of funding for IT research and development; and academic researchers, who are net recipients of that funding. This analysis focuses on the funding of research, development, and innovation from the point of view of those who provide it, ignoring the crucial role that many of those participants also play in creating and disseminating information technology by buying and defining that technology as consumers. This memorandum also focuses only on research and development spending by U.S. entities; it excludes investments by foreign companies, governments, and universities.

TOTAL SPENDING ON RESEARCH AND DEVELOPMENT IN THE INFORMATION TECHNOLOGY SECTOR

In 1997, the most recent year for which complete information exists, private industry provided the lion's share of funding for research and development (R&D) in the information technology sector (see Table 1). Funds from venture capital firms ran a distant second, and the federal government contributed the smallest amount. Those sources tend to spend their money on different things, however. Private companies and venture capitalists focus more of their spending on short-term development of products. Venture capital funding also covers such non-R&D expenses as capital investment and marketing. Federal funding, by contrast, is more concentrated in long-term basic research. Consequently, despite its small size, federal funding may have a disproportionately large effect on the direction that information technology takes in the long run. (CBO could find no information

TABLE 1. SPENDING ON INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT, BY SOURCE OF FUNDS, 1997

Source of Funds	Funding Level (Billions of dollars)	Typical Activity
Industry	44.2	Developing new computers or data communications devices or software
Venture Capital	6.9	Funding new companies to bring new products to market
Federal[a]	1.2	Using high-end computers to solve problems in basic science

SOURCE: Congressional Budget Office based on data from National Science Foundation, *Research and Development in Industry, 1997* (1999); National Coordination Office for Computing, Information, and Communications, *Computing, Information, and Communications: Networked Computing for the 21st Century* (August 1998), and *High Performance Computing and Communications: FY 1998 Implementation Plan* (September 1998); and Venture Economics Information Services.

NOTE: Industry and venture capital spending is for calendar year 1997. Federal spending is for fiscal year 1997.

a. Includes only technology development programs from the High Performance Computing and Communications initiative and the Department of Energy.

about the amount of IT funding that universities, colleges, and independent research institutes contribute from their endowments or from state appropriations.)

In absolute terms, the information technology sector now receives one-third of all corporate spending on R&D in the U.S. economy. Similarly, the venture capital funds going to the IT sector represent more than half of all venture capital funding in the economy.

WHAT CONSTITUTES THE INFORMATION TECHNOLOGY SECTOR?

As this memorandum defines it, the information technology sector comprises five main industries:

- Computer, accounting, and business machines;
- Communications equipment;
- Electronic components;
- Communications services, including telephone services; and
- Computer and data-processing services.[1]

Many analysts do not include the industry that produces electronic components, such as semiconductors and printed circuit boards, in their definition of the IT sector. However, that exclusion fails to recognize the changing relationship between the computer industry and the suppliers of its components. Many manufacturers of personal computers do little research and development of their own, relying instead on the R&D performed by component manufacturers for

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1. Those are the standard industrial classification designations that the Bureau of the Census uses in reporting on industrial activity.

their technological impetus. Only part of that R&D benefits the IT sector, however; the automotive industry and consumer electronics other than computers and communications equipment are also large direct consumers of electronic components.

According to data from the Bureau of the Census, the output of the U.S. information technology sector totaled $845 billion in 1997, the last year for which complete data are available (see Table 2).[2] Excluding electronic components, that output was $717 billion. Between 1993 and 1997, the IT sector grew at an average rate of 12.3 percent a year (or 11.7 percent if electronic components are excluded). Because prices in the sector have largely been declining, the growth rate of output adjusted for inflation is probably even higher than that. Moreover, although prices have been falling, product quality has been improving markedly, further increasing the sector's total output.

By way of comparison, the nation's inflation-adjusted gross domestic product (GDP) grew at an average rate of just 3 percent per year between 1993 and 1997. Of course, since several IT industries produce inputs for each other, their net contribution to GDP would be different from their total output.

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2. The Census Bureau uses the value of shipments to measure output from manufacturing industries and total revenue to measure output from service industries, which do not “ship” anything. The IT sector includes both manufacturing and services; consequently, its output estimate includes both measures.

TABLE 2. OUTPUT OF INFORMATION TECHNOLOGY INDUSTRIES, CALENDAR YEARS 1993-1997 (In billions of dollars)

Industry	1993	1994	1995	1996	1997
Office, Computing, and Accounting Machines	55	65	76	83	82
Electronic Components	71	93	119	122	128
Communications Equipment	40	47	53	62	71
Communications Services	247	267	291	322	348
Computer and Data-Processing Services	118	136	156	184	216
Total	531	607	696	775	845
Total Excluding Electronic Components	460	514	577	653	717

SOURCE: Congressional Budget Office based on data from Bureau of the Census, *Current Industrial Reports, 1997 Service Annual Survey*, and *1997 Annual Survey of Communication Services*.

FEDERAL FUNDING FOR INFORMATION TECHNOLOGY R&D

As noted above, the President's Information Technology Advisory Committee has proposed doubling the current level of federal funding for IT development over five years. That funding doubled between 1991 and 1995, but since then its growth has been slower, only 35 percent. The federal funding for information technology R&D discussed in this memorandum is only funding that forms part of the High Performance Computing and Communications program and the Department of Energy’s strategic stockpile management programs. Although those programs are the main federal initiatives for technology development, other federal programs may be investing in IT development as part of their mission.

Different Measures of Federal Spending

Funding for the major federal IT initiatives totals $1.4 billion to $1.5 billion a year. Within that total, spending on the High Performance Computing and Communications program has been stable for five years, whereas spending on the Department of Energy's Accelerated Strategic Computing Initiative and stockpile computing program has been growing since those programs began in 1996 and 1998, respectively (see Table 3).

Those figures miss some federal spending on information technology, however. An alternative measure of federal efforts to promote IT research comes from the annual surveys of federal research managers conducted by the National Science Foundation (NSF)—particularly those of research managers in two IT-related fields, electrical engineering and computer science.[3] The data from those surveys, which are available through 1996, reflect funding for both applied and basic research for all entities that perform such research: federal, industry, academic, and other facilities.

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3. Other fields of science obviously play a role in the development of information technology, but their relationship to that area is more difficult to separate out.

TABLE 3. FUNDING FOR CURRENT FEDERAL PROGRAMS THAT FOCUS ON INFORMATION TECHNOLOGY (By fiscal year, in millions of dollars of budget authority)

	1991	1992	1993	1994	1995	1996	1997	1998	1999
High Performance Computing and Communications Initiative	489	655	795	938	1,129	1,043	1,009	1,070	1,041
Department of Energy Accelerated Strategic Computing Initiative	a	a	a	a	a	86	152	224	301
Stockpile Computing	a	a	a	a	a	a	a	151	183

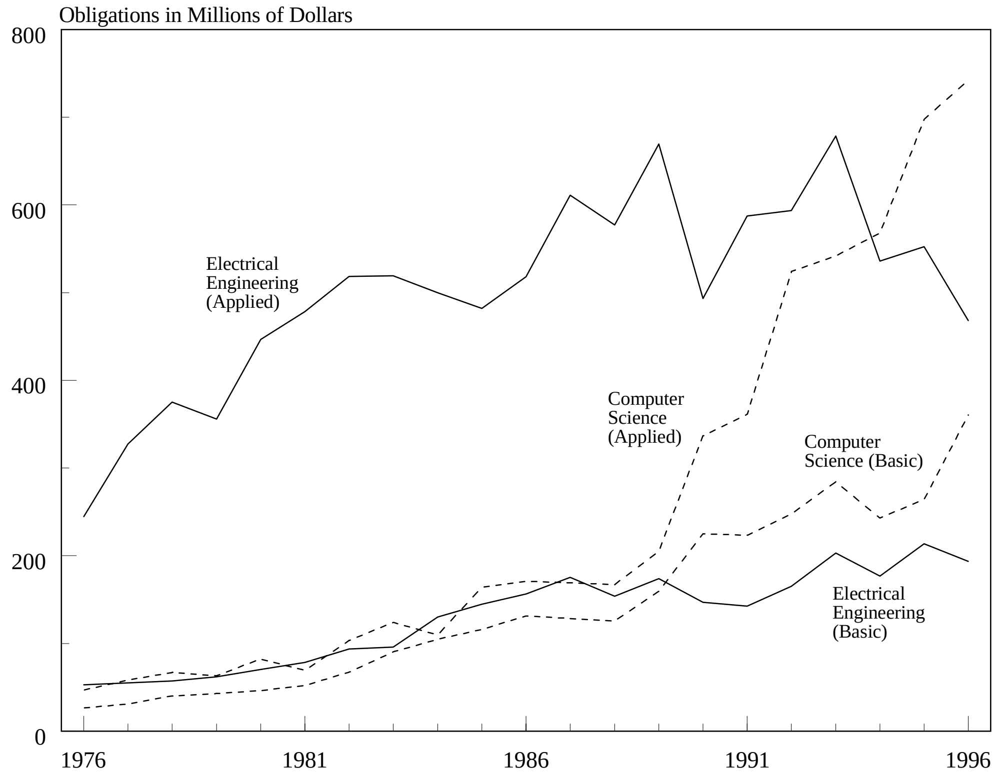
SOURCE: Congressional Budget Office based on National Coordination Office for Computing, Information, and Communications, *Computing, Information, and Communications: Networked Computing for the 21st Century* (August 1998), and *High Performance Computing and Communications: FY 1998 Implementation Plan* (September 1998).

NOTE: Excludes some mission-related research and development performed by other federal programs.

a. This program did not exist in this year.

Federal spending on computer science research, whether applied or basic, has risen substantially over the past 20 years (see Figure 1). During the 1990s, it more than tripled for applied research. By contrast, federal spending on electrical engineering has fluctuated—rising and falling several times since the mid-1980s in the case of applied research, and rising more steadily but at a much lower rate in the case of basic research. Adjusted for inflation, federal spending on both IT-related fields presents a simple story: funding for computer science research is increasing, whereas funding for electrical engineering research is stagnant or declining.

FIGURE 1. TOTAL FEDERAL FUNDING FOR RESEARCH RELATED TO INFORMATION TECHNOLOGY, FISCAL YEARS 1976-1996



SOURCE: Congressional Budget Office based on data from National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 1996, 1997, and 1998*, vol. 46 (1998).

A comparison of the data in Table 3 and Figure 1 suggests that the program totals in Table 3 probably undercount the total federal IT effort. According to the NSF surveys, federal agencies spent $1.1 billion on computer science in 1996—roughly the same amount that the main federal IT programs spent that year. The major difference is in the area of electrical engineering, especially hardware development involving electronic components and other things below the computer system level. The bulk of the computer science spending shown in Figure 1 is probably included in the numbers in Table 3, but only a portion of the federal spending on electrical engineering is.[4]

Federal spending on electrical engineering research is only partly related to IT development, however. A great deal of federal research in that area is focused on developing sensors and other specialized military equipment that may not have any role in information technology. But other federal research on electronic components—such as the long-standing effort to develop high-performance substitutes for silicon in semiconductors—may end up playing an important role in civilian wireless communications.

Federal Spending by Agency

Federal funding for applied research in computer science has been driven by the needs of the Department of Defense (DoD) until quite recently (see Table 4). In 1990, for example, DoD research accounted for 80 percent of all such federal funding. By 1996, however, that share had fallen to 55 percent. Department of Energy programs account for most of the growth in nondefense spending.[5]

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4. Of course, not all federal spending on computer science is contained within the programs listed in Table 3, but the overlap is large.

5. The data in Table 4 may understate the National Aeronautics and Space Administration's (NASA's) role in information technology spending. A disproportionate amount of NASA's spending is in a catchall category called Mathematics and Computer Science Not Elsewhere Classified. The precise allocation of those funds is not clear, but including them would not change the picture materially.

TABLE 4. FEDERAL FUNDING FOR COMPUTER SCIENCE RESEARCH, BY AGENCY, FISCAL YEARS 1986-1996 (Obligations in millions of dollars)

	Department of Defense	Department of Energy	National Aeronautics and Space Administration	National Science Foundation	Other Agencies	Total
			Applied Research			
1986	124	5	20	1	21	171
1987	111	5	27	2	24	169
1988	113	5	23	3	23	167
1989	146	5	26	4	25	205
1990	270	5	23	12	27	337
1991	219	64	27	8	44	361
1992	335	92	25	20	53	524
1993	361	83	7	9	93	552
1994	381	73	8	15	92	568
1995	443	80	9	9	171	711
1996	407	187	8	15	140	757
			Basic Research			
1986	40	25	20	44	3	131
1987	38	10	19	58	3	129
1988	42	11	17	52	3	125
1989	55	12	22	67	3	160
1990	85	18	22	97	3	225
1991	70	23	24	99	8	224
1992	92	25	19	104	8	248
1993	112	21	17	118	16	284
1994	74	17	18	131	3	243
1995	100	17	18	116	13	264
1996	67	14	18	231	31	361

SOURCE: Congressional Budget Office based on data from National Science Foundation, *Federal Funds Survey, Fields of Science and Engineering Research Historical Tables, Fiscal Years 1970-98* (1998).

For basic research in computer science, federal funding was divided almost in half between DoD and the National Science Foundation at the beginning of the decade, with other agencies playing lesser roles (see Table 4). By 1996, however, NSF spending for computer science accounted for almost two-thirds of federal spending in that area—a consequence of the High Performance Computing and Communications initiative.

CORPORATE SPENDING ON INFORMATION TECHNOLOGY R&D

Data on IT research and development by private industry can be helpful to policymakers trying to decide whether to double the current level of federal funding over the next five years. Is the IT sector investing enough in R&D, both in absolute terms and relative to its size? Furthermore, are those funds being invested in the kinds of research that will produce benefits for the long run, or are they focused on the details of product development? Available data suggest that the IT sector is investing sufficiently overall, but it is disproportionately focusing on short-run investments in product development.

Current Data on Industry R&D

The National Science Foundation collects R&D data by company rather than by establishment (such as an individual factory) as the Census Bureau does for its industrial output statistics. In the NSF data series, all of a company's R&D is allocated to the single largest activity (measured by payroll) in which the company is engaged. Thus, a company that conducts a variety of activities in information technology would be classified as conducting only one. Small changes in a large company's payroll can therefore result in apparently large changes and discontinuities in industry data series that stem mainly from the method of classification, not from changes in allocation of R&D resources. Because large companies typically shift among industries within the IT sector—say, from communications equipment to communications services—the data for the total sector should not be affected by those shifts in classification, but changes in individual industries may be misleading.

Overall R&D Levels

Companies in the IT sector spent $44.2 billion on research and development in 1997, the most recent year for which data exist (see Table 5). That spending represents about one-third of all corporate spending on R&D in the U.S. economy. Between 1993 and 1997, the IT sector increased its investment in R&D by an

TABLE 5. NONFEDERAL SPENDING ON INDUSTRIAL R&D, BY INDUSTRY, CALENDAR YEARS 1993-1997 (In billions of dollars)

Industry	1993	1994	1995	1996	1997
Office, Computing, and Accounting Machines	4.9	4.1	4.7	8.1	12.8
Electronic Components	5.1	5.9	9.6	12.5	10.8
Communications Equipment	4.0	4.9	3.8	4.4	7.4
Communications Services	4.3	4.2	4.8	4.0	1.9
Computer and Data-Processing Services	6.9	5.7	8.5	10.0	11.3
Total	25.2	24.8	31.5	39.0	44.2
Memorandum:					
All Industries	94.6	97.1	108.7	121.0	133.6

SOURCE: Congressional Budget Office based on data from National Science Foundation, *Research and Development in Industry, 1997* (1999).

average of 15 percent a year, or a total of $19 billion. If the electronic components industry is excluded from the IT sector, growth in R&D averaged 14 percent a year, and total corporate R&D funding in 1997 was $33.4 billion. Because of the swings in company classification, however, that subtotal is less reliable than the total for the entire IT sector; the data suggest that some companies were reclassified between 1996 and 1997.

R&D Relative to Industry Sales

According to the National Science Foundation, the information technology sector spends much more on research and development, relatively speaking, than industry as a whole does—6.1 percent of net sales in 1997 compared with less than 3 percent (see Table 6).[6] That comparison is possible only for years since 1995, however. Before that, the NSF did not report IT industries separately from nonmanufacturing industries in general.

Although the general level of funding might indicate which industries are more R&D intensive, a fluctuation or even a long-term decline in the ratio of R&D to sales does not necessarily mean that the sector is decreasing its commitment to research and development. Information goods are typically characterized by high fixed costs and low variable costs. A certain level of R&D is required to develop a computer, a software package, or some other IT product. Once that product has been developed, the company can sell 1,000 or 1 million copies without performing additional research and development. The ratio of R&D to sales will decline as the number of copies sold increases, but that does not mean that the company is any less technologically adept, just that its market has grown. Since the IT sector is

6. Net sales should not be confused with the value of shipments. One is on a company basis; the other uses establishments. Furthermore, the NSF data are for net sales (that is, sales minus returns and other adjustments) only of companies performing R&D; the shipment data are for all establishments in the industry.

TABLE 6. CORPORATE R&D SPENDING AS A PERCENTAGE OF NET SALES OF ALL COMPANIES PERFORMING R&D, BY INDUSTRY, CALENDAR YEARS 1995-1997

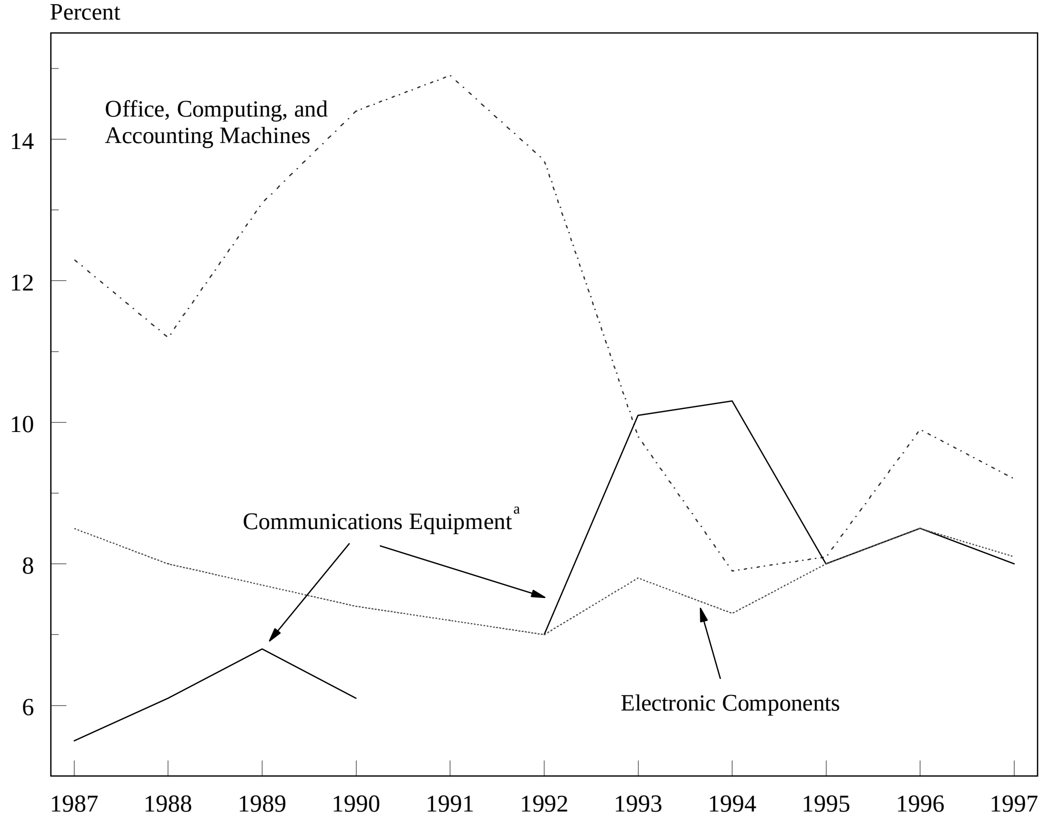
Industry	1995	1996	1997
Office, Computing, and Accounting Machines	8.1	9.9	9.2
Electronic Components	8.0	8.5	8.1
Communications Equipment	8.0	8.5	8.0
Communications Services	2.2	1.9	0.7
Computer and Data-Processing Services	11.1	12.4	13.3
Sales-Weighted Average	6.0	6.8	6.1
Memorandum:			
All Industries	2.8	3.0	2.9

SOURCE: Congressional Budget Office based on data from National Science Foundation, *Research and Development in Industry, 1997* (1999).

growing very rapidly, its ratio would be expected to vary and even decline over time even as IT firms increased their investment in R&D.

To provide some background, Figure 2 presents a 10-year time series of the ratio of R&D spending to net sales for the manufacturing segments of the IT sector: computers and office equipment, communications equipment, and electronic components. Clearly, those three industries have moved in very different directions.

FIGURE 2. CORPORATE R&D SPENDING AS A PERCENTAGE OF NET SALES OF ALL COMPANIES PERFORMING R&D, BY INDUSTRY, CALENDAR YEARS 1987-1997



SOURCE: Congressional Budget Office based on data from National Science Foundation, *Research and Development in Industry, 1997* (1999).

a. Data for communications equipment were not available for 1991.

The most dramatic change is the steep decline in the ratio of R&D to sales in the computer industry (labeled "Office, Computing, and Accounting Machines" in Figure 2). The decline in the market share of the International Business Machine (IBM) Corporation and other integrated computer manufacturers explains a large part of that drop.[7] When those companies enjoyed dominant market shares, they were able to capture much of the economic benefits (most notably the profits) generated by the innovative products that their R&D created. When other firms with less R&D overhead moved in and secured a larger part of the market for computers, IBM and the other integrated computer companies were less able to capture the benefits of their R&D investments. They therefore reduced the share of sales they spent on research and development.

The increase in the R&D-to-sales ratio in the communications equipment industry is probably correlated with a decline in market concentration associated with the breakup of the Bell network. That breakup moved the net sales revenue of regional Bell operating companies into communications services and out of communications equipment. Census Bureau rules preclude disclosing which companies are classified in which industries, so the above explanations involve some speculation.

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7. Integrated computer manufacturers such as IBM and Digital Equipment Corporation made many of their own components and sold a broad range of computer types.

R&D by Category

Some analysts argue that IT companies are underinvesting in basic research, even when their overall investment in R&D appears strong. Because the market for information technology is growing so rapidly, those analysts contend, resources that might have gone into long-term research are being diverted into projects with higher prospects for short-term payoffs.

The division between basic and applied research is always somewhat arbitrary but especially so in the IT sector. Because the intent of IT research is to improve information technology, such research is almost always, by definition, applied. Some policy analysts therefore distinguish research by time frame rather than by type: research that is likely to be brought to the marketplace in less than five to seven years versus research that has a longer time frame.[8] The NSF data, however, do not permit such an analysis.

As noted above, those data indicate that the IT companies invested $44.2 billion in R&D in 1997. Of that amount, $31.7 billion went for development and $12.4 billion for research (see Table 7). Within the category of research, the IT sector (excluding communications services) spent $1.4 billion on basic research and $10.3 billion on applied research. (In the interests of confidentiality, the NSF did

8. Many analysts argue that with the Internet, IT firms now have an even shorter time horizon, measured in months rather than years.

TABLE 7. CATEGORIES OF NONFEDERAL SPENDING ON R&D FOR THE INFORMATION TECHNOLOGY SECTOR, CALENDAR YEAR 1997 (In billions of dollars)

Industry	Research: Basic	Research: Applied	Research: Total	Development	Total R&D
Office, Computing, and Accounting Machines	0.2	3.8	4.0	8.8	12.8
Electronic Components	0.4	4.2	4.6	6.2	10.8
Communications Equipment	0.1	1.1	1.3	6.1	7.4
Communications Services	a	a	0.7	1.1	1.9
Computer and Data-Processing Services	0.6	1.2	1.9	9.4	11.3
Total	1.4[b]	10.3[b]	12.4	31.7	44.2
Memorandum: All Industries	8.8	29.8	38.5	95.1	133.6

SOURCE: Congressional Budget Office based on data from National Science Foundation, *Research and Development in Industry, 1997* (1999).

a. Not published separately.

b. Excludes communications services.

not break down data for the communications services industry further because doing so might reveal too much about the activities of a single company.)

Although overall, the IT sector's effort in basic and applied research in 1997 represented almost a third of all research performed by industry, in percentage terms, the sector performed less research and more development than industry as a whole. Similarly, within the research category, the IT sector accounted for 16 percent of all basic research by industry but performed less basic research than its overall level of R&D would have suggested (see Table 7).

VENTURE CAPITAL INVESTMENT IN THE INFORMATION TECHNOLOGY SECTOR

Venture capital firms play an important role in the IT sector. They typically raise funds from private investors—usually organizations and wealthy individuals—and invest those funds in often-risky new ventures that offer the prospect of a high payoff. An individual or group trying to start a company to sell a new product or service typically offers part ownership to a venture capital firm in exchange for funding. Besides funding, venture capital firms often provide management and other nontechnical assistance. Those firms hope to profit when the new company is sold to a larger one or starts selling stock on the major exchanges. The U.S. market for venture capital is the envy of the industrialized world, and its ability to move resources rapidly into areas perceived as "hot" is legendary.

According to Venture Economics Information Services, a company that tracks venture capital firms, such firms invested $46.6 billion in start-up companies in all industries between January 1, 1995, and December 31, 1998. The IT sector accounted for $26 billion—or 56 percent—of that total (see Table 8). Within the sector, roughly half of the venture capital investment went to computer software

TABLE 8. INVESTMENT BY VENTURE CAPITALISTS IN INFORMATION TECHNOLOGY AND OTHER INDUSTRIES, JANUARY 1, 1995, THROUGH DECEMBER 31, 1998

Industry	Amount of Investment (Millions of dollars)
Information Technology	
Computer software and services	12,722
Communications	8,054
Semiconductors and other electronic components	2,659
Computer hardware	2,529
Subtotal	25,964
Other Industries	
Medical and health related	6,624
Other products	4,786
Consumer related	4,000
Biotechnology	3,670
Industrial and energy	1,593
Total[a]	46,636

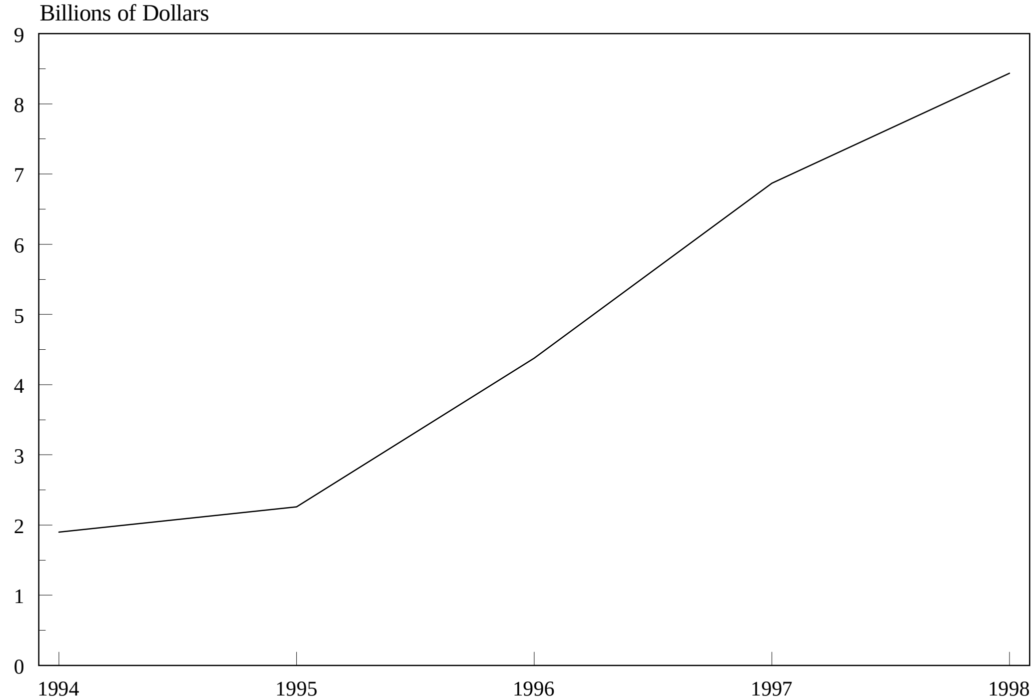
SOURCE: Congressional Budget Office based on data from Venture Economics Information Services.

a. Includes disbursements in a miscellaneous category that total less than $1 million.

and services companies, with electronic components and computer hardware companies accounting for much smaller fractions.

Between 1994 and 1998, venture capital firms quadrupled their investment in the IT sector—from a little less than $2 billion to an estimated $8 billion (see Figure 3). The jump may have been even greater than that: estimates for the latest years are likely to be revised upward as more funds are reported.

FIGURE 3. INVESTMENT BY VENTURE CAPITALISTS IN THE INFORMATION TECHNOLOGY SECTOR, CALENDAR YEARS 1994-1998



SOURCE: Congressional Budget Office based on data from Venture Economics Information Services.

Not all of the IT funding provided by venture capitalists is devoted to technology development efforts; some is used to produce and sell start-up firms' new products. However, CBO has no way of estimating what share of total investment goes toward technology development.

Some analysts argue that venture capital does not represent funding for new R&D for industry. They contend that the technology pursued by most venture capital firms has been conceived and sometimes proved at another corporation or an academic laboratory—the new firm is not creating new ideas.

But even if that is the case, venture capital complements the investment capital of existing companies. Existing companies commercialize the technological breakthroughs they deem most profitable, using either technology they have developed or technology they obtain from academia or government laboratories. By funding ideas that existing companies will not back, venture capitalists are second-guessing the judgment of existing companies about the economic potential of new technologies. Consequently, venture capitalists increase the number of new ideas introduced into the economy from the stock of ideas generated in the laboratory. In other words, they raise the efficiency of existing R&D by raising the rate at which ideas developed in the laboratory are brought to market. Thus, venture capital funds may be more important as a technological lubricant—making the process of getting to market easier—than as a source of funding for new R&D.

ACADEMIA'S RESOURCES FOR INFORMATION TECHNOLOGY R&D

The Administration's proposal raises two sets of questions about the academic resources available for research and development in the IT sector. First, has the stage for continued growth in information technology been set by ensuring that academia has the resources to produce enough new ideas and new students to meet the economy's needs? Those needs are hard to measure precisely. A first approximation would be to determine whether the funds for academic research and the number of people involved in such research are growing substantially. Second, do colleges and universities have the ability to use extra resources efficiently?

This section presents data on the stocks and flows of human and financial resources in academia as background for considering those questions. Although much of the funding for academic research comes from the federal government or industry, academic institutions also fund some of their own research. However, CBO was unable to find any data on academic research by field of study that was funded from university endowments, tuition receipts, or state government appropriations.

Financial Resources

Spending on science and engineering research at colleges and universities has been increasing recently. In 1992, total spending on such research was $18.8 billion, but by 1997 that figure had risen to $24.3 billion—an increase of 29 percent (see Table 9). Spending on research in fields related to information technology rose by slightly more, 30 percent—from $1.5 billion in 1992 to just under $2 billion in 1997. The share of all academic funding for science and engineering that was devoted to IT-related disciplines fluctuated around 8 percent during that period.

TABLE 9. SPENDING FOR SCIENCE AND ENGINEERING RESEARCH AT ACADEMIC INSTITUTIONS (By fiscal year, in millions of dollars)

	1992	1993	1994	1995	1996	1997
R&D Related to Information Technology						
Electrical engineering	703.7	698.1	742.5	817.2	885.8	948.9
Computer science	555.4	607.7	648.1	687.2	696.8	718.7
Mathematics	247.6	272.2	282.3	280.7	290.6	293.4
Subtotal	1,506.7	1,578.0	1,672.8	1,785.2	1,873.3	1,961.0
Total Science and Engineering R&D	18,816.1	19,948.3	21,050.7	22,202.7	23,092.0	24,348.3
Information Technology R&D as a Percentage of Total Science and Engineering R&D	8.0	7.9	7.9	8.0	8.1	8.1

SOURCE: Congressional Budget Office based on data from National Science Board, *Science and Engineering Indicators, 1998* (Arlington, Va.: National Science Foundation, 1998), p. A204.

Defining exactly which university resources feed into the IT sector is not straightforward: research and researchers from many fields have contributed to advances in information technology. Nonetheless, the basic assumption should be that the research and people available to the IT sector are related to the funding of academic training and research in that area. The three research areas shown in Table 9—electrical engineering, mathematics, and computer science—feed more or less directly into the IT sector.[9] Computer science is very directly related.

9. Fields such as plasma physics, condensed matter physics, and materials research are also crucial to the continued development of information technology. But the research in those fields has such wide use in the economy that assigning any given portion of it to the information technology sector is difficult.

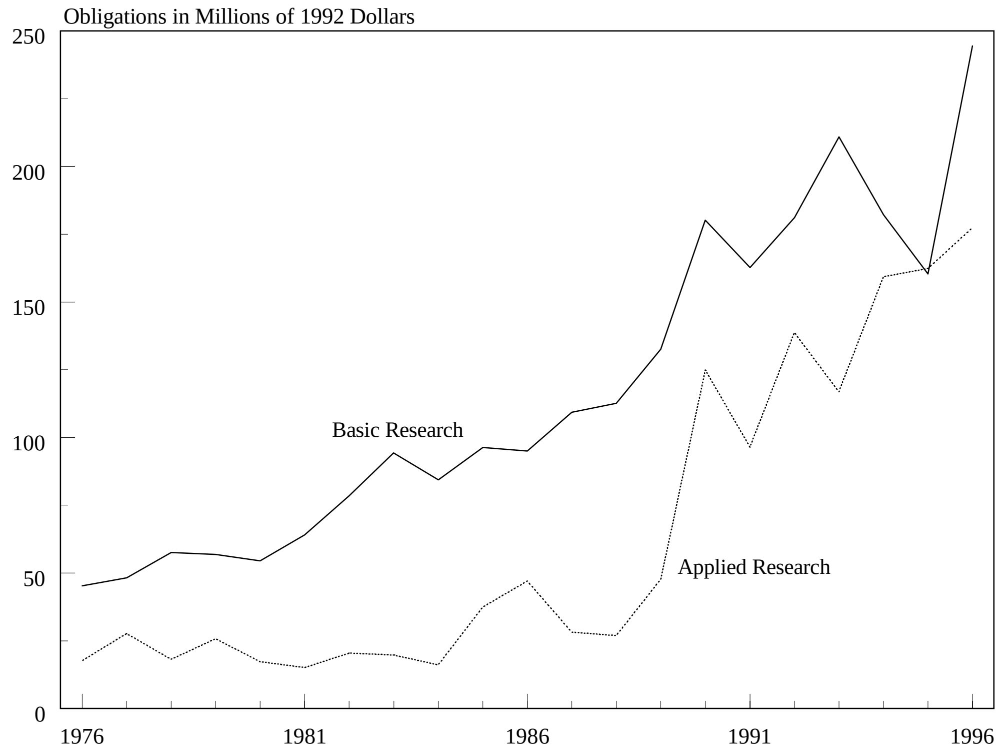
Similarly, electrical engineering is probably fairly relevant to the IT sector. Mathematics, being the language of science, can vary widely in its uses.

Federal spending on academic research in computer science has been growing rapidly in both applied and basic areas (see Figure 4). Between 1990 and 1996 (the last year for which CBO could find data), federal spending on basic research in computer science at academic institutions grew by 5 percent annually, and spending on applied research grew by 6 percent annually, after adjusting for inflation.[10]

To some extent, those growth rates may overstate the federal commitment to basic research in information technology. Dividing IT-related research into "basic" and "applied" categories is problematic since, as was previously noted, all such research could be viewed as applied in some sense. Some of what is termed research is focused on short-term goals. For example, in the so-called Grand Challenges of the High Performance Computing and Communications initiative, much of the research focuses on using supercomputers and other high-end computers to provide insight into very basic research problems in physical or natural sciences, such as weather patterns or the structure of the atom or the human genome. In those programs, a large portion of the research that is funded is

10. National Science Foundation, *Federal Funds Survey, Detailed Historical Tables, Fiscal Years 1951-98*, (1998), Tables 62, 63, and 64.

FIGURE 4. FEDERAL FUNDING TO UNIVERSITIES AND COLLEGES FOR BASIC AND APPLIED RESEARCH IN COMPUTER SCIENCE, FISCAL YEARS 1976-1996



SOURCE: Congressional Budget Office based on data from National Science Foundation, *Federal Funds Survey, Detailed Historical Tables, Fiscal Years 1951-98* (1998).

considered basic research because its goal is basic understanding of natural phenomena. However, the information technology components of those research projects are likely to focus on tools to make the specific application go faster, not on longer-term information technology issues. Thus, the research may be basic in its physical science component but not in its computer science component.

Human Resources

Many policymakers and analysts concerned with information technology have raised questions about whether enough scientists are available to conduct academic research and train new researchers. Data from the Department of Education suggest that there are around 26,000 full- and part-time computer science faculty at institutions of higher learning (see Table 10). Those personnel constitute more than one-sixth of the natural science faculty at U.S. universities. Mathematics faculty also frequently teach computer-related courses, increasing the number of instructors involved in information technology. Both computer science and mathematics have a high ratio of part-time to full-time faculty. Whereas in other sciences roughly three-quarters of the faculty are full time, in those areas only half of the faculty are. That pattern is atypical in the natural sciences, but it occurs frequently in other disciplines, such as business, communications, and even fine arts. In the case of law, there are more part-time faculty than full time. Thus, unlike other natural sciences, computer science seems to have a pattern more typical of a professional school.

The number of computer science instructors and researchers in colleges and universities who hold doctoral degrees has been rising rapidly over the past two decades (see Table 11). Roughly 3,100 computer science teachers had doctorates in

TABLE 10. DISTRIBUTION OF FULL- AND PART-TIME INSTRUCTIONAL FACULTY AND STAFF IN THE NATURAL SCIENCES AT INSTITUTIONS OF HIGHER EDUCATION, FALL 1992

Field	Full Time	Part Time
Biological Sciences	34,289	11,747
Physical Sciences	28,313	10,626
Mathematics	25,325	24,559
Computer Science	13,578	13,310
Total	101,505	60,242

SOURCE: Congressional Budget Office based on data from Department of Education, National Center for Education Statistics, *National Study of Postsecondary Faculty, 1993* (September 1996).

1995, up tenfold from 1981.[11] The fact that they still represent a small percentage of all computer science faculty members may not be surprising. Typically, less than 20 percent of university science faculty have Ph.D.s—the type of degree that would make them eligible to lead a research team.[12] However, that does not mean that other faculty members are not engaged in research. In most years, over 80 percent of computer science faculty describe research as one of their primary duties, although that number has fallen slightly in recent years.

The number of doctoral degrees that U.S. colleges and universities confer in such IT-related fields as mathematics and computer science has been rising

11. Mathematics faculty with Ph.D.s made up a much larger group, but the number of mathematics professors who do research in computer-related fields as opposed to statistics or other fields open to them is not clear. There may be some degree of overlap.

12. Department of Education, National Center for Education Statistics, *National Study of Postsecondary Faculty, 1993* (September 1996).

TABLE 11. DOCTORAL-LEVEL ACADEMIC FACULTY IN COMPUTER SCIENCE AND MATHEMATICS (In thousands)

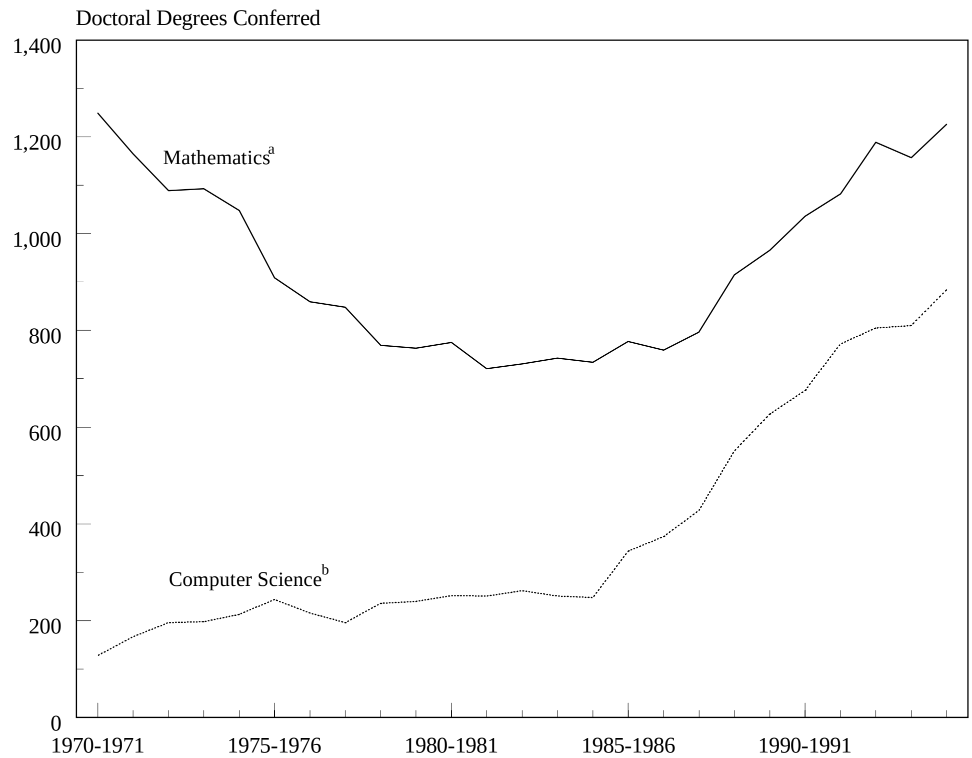
Field	1981	1983	1985	1987	1989	1991	1993	1995
Computer Science								
All faculty with doctorates	0.3	0.5	0.8	1.1	1.5	2.0	2.5	3.1
Postdoctoral and other part-time faculty	0	0	0	0	0	0	0	0.1
Mathematics	12.4	12.9	13.6	13.8	14.5	15.2	15.5	14.6
Memorandum:								
All Science and Engineering	167.1	176.2	190.3	196.0	206.7	210.6	213.8	217.5

SOURCE: Congressional Budget Office based on data from National Science Board, *Science and Engineering Indicators, 1998* (Arlington, Va.: National Science Foundation, 1998), pp. A227-A228.

dramatically since the mid-1980s (see Figure 5). Before that, mathematics degrees experienced a decline, but computer science degrees have shown a steady increase for the past 30 years—although that increase has accelerated recently. Between 1991 and 1995, the number of Ph.D.s conferred in computer science jumped by 31 percent. The President's Information Technology Advisory Committee (PITAC) reports, on the basis of a nongovernmental survey, that close to 1,000 new doctoral degrees in computer science are now being given each year.

A significant share of those degrees are conferred on foreign citizens, many of whom will return to their countries. Consequently, not all of those Ph.D.s represent new innovative capacity for the U.S. information technology sector. But while foreign students are working on research projects at U.S. universities, they are contributing to the types of fundamental research that PITAC's IT^2 plan is intended to fund.

FIGURE 5. DOCTORAL DEGREES IN COMPUTER AND INFORMATION SCIENCES AND MATHEMATICS CONFERRED BY INSTITUTIONS OF HIGHER EDUCATION, ACADEMIC YEARS 1970-1971 TO 1994-1995



SOURCE: Congressional Budget Office based on data from Department of Education, National Center for Education Statistics, Higher Education General Information Survey and Integrated Postsecondary Education Data System.

a. Includes degrees in statistics.

b. Includes degrees in general computer and information sciences, computer programming, data-processing technology/technician, information science and systems, computer systems analysis, and other information sciences.

Capacity Constraints

One way to assess the strain that the IT^2 initiative might place on human resources at colleges and universities is to look at the level of resources that current programs are using. As noted above, the largest increase in IT funding in the President's budget for fiscal year 2000 ($146 million) would go to the National Science Foundation—$110 million for the NSF's Directorate for Computer and Information Science and Engineering (CISE) to pay for academic research, and the rest for equipment purchases at the NSF's research and development facilities. The budget also requests another $14 million for CISE, which, together with the aforementioned $110 million, would increase its funding by 42 percent from the 1999 level of $299 million (see Table 12).

If fully funded, the IT^2 initiative would add 700 senior researchers and a total of 1,700 extra staff to the number of people working on research paid for by CISE—an increase of 33 percent from the 1999 level. If funding for IT^2 rises in the initiative's later years, as PITAC has proposed, presumably the personnel requirements will also rise from current levels.

TABLE 12. NUMBER OF PEOPLE INVOLVED IN CISE ACTIVITIES, FISCAL YEARS 1996-2000

	Actual			Estimated	
	1996	1997	1998	1999	2000
Senior Researchers	1,610	1,678	1,548	1,720	2,400
Other Professionals	1,420	1,071	783	870	1,200
Postdoctoral Faculty	150	171	260	290	400
Graduate Students	1,639	1,645	1,735	2,020	2,500
Undergraduates	394	696	320	370	500
Total	5,213	5,261	4,646	5,270	7,000
Memorandum:					
CISE Activity Funding (In millions of dollars)	263	273	269	299	422

SOURCE: Congressional Budget Office based on data from the National Science Foundation's budget submission, various years.

NOTE: CISE = Directorate for Computer and Information Science and Engineering.

THE PITAC PROPOSAL TO BOOST FEDERAL FUNDING FOR INFORMATION TECHNOLOGY

PITAC asserts that too much of the IT sector's research and development effort is focused on solving near-term problems, and too little is focused on structural impediments that will keep computers and data communications from fulfilling their full potential. Overcoming those impediments requires fundamental research into the writing of computer software and data communications. Federal agencies have always provided the funding for that type of research, which has proved crucial in the growth of the IT industry. But PITAC argues that federal R&D efforts have not kept pace with the growth of the sector. The committee contends that basic research in software and data communications is underfunded relative to the problems the sector faces and the potential return to society from solving those problems.

PITAC proposes a broad research agenda and funding increases in five areas (four involving research and one acquisition):

- *Software*, including fundamental research into software development methods (for example, human/computer interfaces such as voice recognition) and into information acquisition and use;

- *Large-scale computer networking*, including research on the behavior and control of the Internet and related applications as they expand to connect billions of computing devices (for example, will the Internet as currently configured be stable when 1,000 times as many devices are connected to it?);

- *High-end computing*, including research on innovative technologies for fast computers, such as new designs and hardware and software (those high-end computers, formerly called supercomputers, are used for forecasting weather, modeling global climate change, and solving other problems that require fast computers);

o *High-end acquisitions*, including purchase of the high-end computers for science and engineering research to ensure that academic researchers have access to the latest technology; and

o *Socioeconomic impact*, including research into how information technology influences work, education, and other processes in the economy and how IT investments affect different segments of society (rich or poor, white or minority, and so forth). This area also includes funds to expand the use of information technology throughout the economy, especially where it is underutilized.

The PITAC initiative would fund each of those five areas at a different level for the first five years (see Table 13). Software research would receive the most

TABLE 13. PROPOSED FUNDING INCREASES FOR THE INFORMATION TECHNOLOGY INITIATIVE (By fiscal year, in millions of dollars)

Research Area	2000	2001	2002	2003	2004
Software	112	268	376	472	540
Large-Scale Computer Networking	60	120	180	240	300
High-End Computing	180	205	240	270	300
High-End Acquisitions	90	100	110	120	130
Socioeconomic Impact	30	40	70	90	100
Total	472	733	976	1,192	1,370

SOURCE: Congressional Budget Office based on data from the President's Information Technology Advisory Committee, *Information Technology Research: Investing In Our Future* (Arlington, Va.: National Coordination Office for Computing, Information, and Communications, February 24, 1999), p. 2.

TABLE 14. PROPOSED BUDGET FOR THE INFORMATION TECHNOLOGY INITIATIVE FOR FISCAL YEAR 2000 (In millions of dollars)

Agency	Fundamental Information Technology Research	Advanced Computing for Science, Engineering, and the Nation	Ethical, Legal, and Social Implications and Workforce Programs	Total
Department of Defense	100	0	0	100
Department of Energy	6	62	2	70
National Aeronautics and Space Administration	18	19	1	38
National Institutes of Health	2	2	2	6
National Oceanic and Atmospheric Administration	2	4	0	6
National Science Foundation	100	36	10	146
Total	228	123	15	366

SOURCE: Congressional Budget Office based on data from the National Coordination Office for Computing, Information, and Communications.

funds—37 percent. The second largest recipient, research on high-end computing (which includes some software research), would get about 25 percent of the funding over the first five years.

In its budget for 2000, the Administration did not follow the PITAC proposal exactly, since the committee's final recommendations were released after the budget submission (which is shown in Table 14). Nor has the Administration yet committed itself to the full five-year program proposed by PITAC. Of the $366 million in the Administrations's budget, $228 million would go toward the first three categories of research in PITAC's program (software, large-scale networking, and high-end computing research), $123 million toward high-end acquisitions, and $15 million toward the socioeconomic impact category. The Administration has not yet formulated funding proposals for the years beyond 2000. However, the total budgets proposed for each of the civilian technology agencies that would fund IT^2 would remain flat or decline in those years. Consequently, to fit increases in information technology R&D into those agencies' budgets, funding for R&D in other technology areas would have to be cut.