Chapter 2

The Environment for R&D in Information Technology in the United States

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Introduction

"Information technology" is a generic term for a cluster of technologies (discussed in detail in ch. 9) that provide automated capabilities for

- data collection;
- data input;
- information storage and retrieval;
- information processing;
- communication; and
- information presentation.

The information technology industry has become an integral component of U.S. industrial strength. In common with other high-technology[1] industries, the robustness of information technology depends in part on a base of research and development (R&D). However, several interacting factors are straining long-established U.S. policies vis-a-vis research and development:

- rising costs and complexity of R&D;
- intensive competition for both domestic and foreign markets;
- limited resources; and
- accelerating technological advances.

This report describes those factors and examines their effects on the information technology industry and its R&D base, raising questions both about current policies and about proposals for improving the competitive position of the United States in international information technology markets.

The world's major countries are coming to view the development of high technology—and particularly information technology-as a key to economic gains, important social objectives, and national defense and prestige. These countries have adopted national industrial policies in information technology, investing hundreds of millions of dollars in the hope of achieving preeminence, both in R&D and in commercial markets. This growth of foreign competition[2]-especially from Japan–has stimulated a concomitant growth of R&D in the United States.

The trend toward internationalizing R&D, manufacturing, and distribution is increasing. American companies are deciding that technological strength can also be improved by licensing technology from other domestic and foreign businesses, by acquiring equity positions in firms with needed technology, and by establishing R&D and manufacturing operations in foreign countries in order to obtain access to rapidly changing commercial applications.

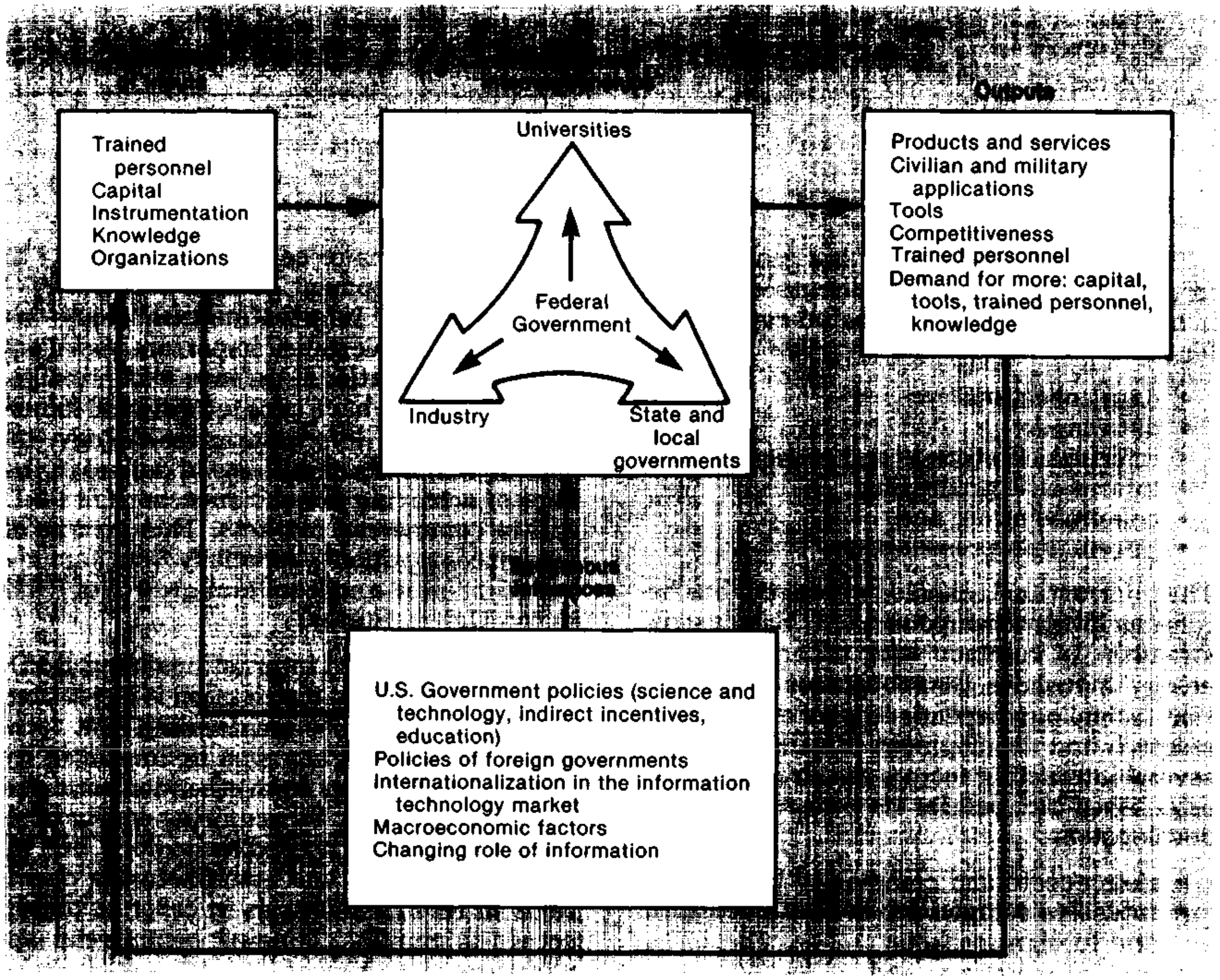
Figure 1 shows some important components of the R&D process and diagrams their interrelationships. The remainder of this report will focus on those components.

- This chapter describes some of the key players in the process and discusses some measures of health of the information technology industry.
- Chapter 3 Presents four case studies, each dealing with an important element in the cluster of technologies that comprise information technology.

'The term high technology is used throughout this chapter to refer to those industries characterized by a high proportion of R&D expenditures per employee, or a significantly larger proportion of skilled workers than the industry average, and a rapidly evolving underlying technological base. Thus computers and electronics are within the scope of this meaning; auto and steel manufacturing are not, in spite of the recent trend to modernize and automate.

'See also *International Competitiveness in Electronics* (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-ISC-200, November 1983).

Figure 1.—Interrelationships in the R&D Process



SOURCE: Office of Technology Assessment.

- Chapter 4 discusses the recent divestiture of AT&T in the context of its potential effect on the R&D activities of Bell Laboratories.
- Chapter 5 considers the availability of trained personnel to the R&D process.
- Chapter 6 examines new university-industry institutional relationships and their changing roles in the R&D environment.
- Chapters 7 and 8 focus on some of the exogenous elements: the science and technology policies of foreign governments in chapter 7; the science and technology policies of the United States in chapter 8.
- Chapter 9 describes the technological underpinnings of information technology, the directions of key research areas, and the characteristics of the information technology industry.

Concepts for R&D

R&D includes a wide variety of activities–ranging from investigations in pure science to product development. Because segments of information technology draw on so many science, engineering and other disciplines—computer science, manufacturing, electrical, mechanical and industrial engineering, physics, chemistry, mathematics, psychology, linguistics—it is difficult to assign particular efforts to the general category of information technology.

As defined by the National Science Foundation (NSF), R&D is categorized as follows:[3]

- *Research is* systematic study directed toward fuller scientific knowledge or understanding of the subject studied.
- In *basic research* the objective is to gain fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications toward processes or products in mind.
- In *applied research* the objective is to gain knowledge or understanding necessary for determiningg the means by which a recognized and specific need may be met.
- Development is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including design and development of prototypes and processes.

The definitions of "applied" and "basic" research are especially troublesome in a field as dynamic as information technology, in which laboratory concepts evolve into marketable products very rapidly. In the area of artificial intelligence, for example, the work is often basic in the sense that it seeks new ways of understanding complex symbolic processes, and applied in the sense that much of the work is directed at prototype applications. This fuzziness has led to differing judgments as to which projects are applied and which are basic, and to confusion in data collection, because the terms are not applied uniformly by Federal agencies, industry, or academia.

Apart from the difficulty in drawing a clean line between basic and applied research, there is an additional problem in identifying the set of industries that collectively comprise the information industry. For purposes of this report, we use the term to include electronics, computer, and telecommunications equipment manufacturers, providers of computer-based services, and commercial software developers.

There are, then, two major areas of ambiguity in any discussion of information technology R&D: ambiguities inherent in designating an effort as "information technology" and ambiguities arising from the overlap of basic and applied research. Because of this, *quantification of R&D efforts in information technology is necessarily approximate and the numbers cited in this report should be regarded as estimates, not as "hard" data.*

One further term, "innovation," should also be clarified. As used in this report, innovation is a process that includes research and development, manufacturing or production, and distribution.[4] The Nation's innovative capacity depends on the effective functioning of all parts of the process. Success in the marketplace requires proficiency in some—not well understood—combination of those parts. There are other factors that influence marketplace success, such as the timing of the introduction of commercial products, the influence of entre preneurs, and a variety of government policies. Thus, while excellence in research and development provides no assurance of leadership in the commercial marketplace, it may very well be a necessary (if not sufficient) ingredient of success.

'National Science Foundation, *Federal Funds for Research and Development Fiscal Years 1981, 1982, and 1983,* Volume XXXI Detailed Statistical Tables, NSF 82-326 (Washington, DC, U.S. Government Printing Office, 1982), p. 1.

'*International Competition in Advanced Technology: Decisions for America,* Office of International Affairs, National Research Council, 1983, pp. 21-22.

The Roles of the Participants and the R&D Environment

Industry, universities, and Government (State, local, and Federal) are the three key contributors to R&Din the United States. The effectiveness of the Nation's R&D is dependent on the vitality of each of the participants and on their interrelationships. Federal support of R&D and Federal policies that maintain a healthy economy encourage industrial investment in R&D.[5] A vigorous industry, in turn, provides a large Federal and State tax base, making possible added support for academic institutions. For their part, well-financed academic institutions generate well-trained personnel as well as the dynamic knowledge base necessary to fruitful R&D efforts.

In addition to describing the roles of each of the participants and the environment for R&D, this section identifies some of the diverse changes taking place in the R&D environment-those already in place, and others in transition-that may profoundly modify some longstanding institutional patterns.

Federal Government Role in R&D

The Federal Government plays several key roles in information technology R&D. As a major *user* of information technology products (about 6 percent of the total automated data processing market and most of the market for supercomputers), its requirements are of considerable interest to the industry. As a *sponsor* of research, the Federal Government funds roughly half of the total R&D carried out in the United States[6] and about two-fifths of the research by the electrical machinery/communications industry (a key component of the information technology complex). In addition, the Federal Government itself *performs* about $11 billion of R&D[7] (table 1) in its own and contract laboratories.

Beyond that, the Government helps to shape the environment in which private firms make their R&D decisions. In some cases, this is a result of deliberate Government policy intended to stimulate (or suppress) industry investment. At other times, the environment is affected by uncoordinated actions—intended to serve other purposes-taken by a variety of Federal entities including the Federal Reserve Board, the courts, regulatory bodies and a plethora of executive branch agencies including the Departments of Justice, Commerce, State, and Defense, the National Security Council, and the Environmental Protection Agency.

Government Funding of R&D in Information Technology

The Federal Government provided about 65 percent of the funding in 1982 for R&D in science and engineering fields in the Nation's

'David M. Levy and Nestor E. Terleckyj, Effects *of Government R&D on* ***Private*** *Investment and* ***Productivity:*** *A* ***Macroeconomic Analysis,*** National Planning Association, revised Jan. 5, 1983, pp. 17-19.

'*Federal Support for R&D and Innovation,* **Congressional Budget Office, April 1984, p. iii.**

'***Probable*** *Levels of* ***R&D Expenditures*** *in 1984:* ***Forecast*** *and Analysis,* **Columbus Division of Battelle Memorial Institute, December 1983, p. 1.**

Table 1 .–Federal Obligations for Total Research and Development: Fiscal Year 1984 (Estimated)
(millions of dollars)

			Extramural[a]							
			United States and Territories							
	Total	Intramural[b]	Industrial firms	FFRDCs[c] administered by industrial firms	Universities and colleges	FFRDCs[c] administered by universities and colleges	Other nonprofit institutions	FFRDCs[c] administered by nonprofit restitutions	State and local governments	Us. supported Foreign[d]
Total all agencies	$45,497.0	$10,969.9	$22,957.4	$1,614.4	$5,270.7	$2,291.9	$1,335.5	$6832	$189.1	$1848

NOTES: [a]All organizations outside the Federal Government that perform with Federal funds,
bAgencies of the Federal *Government.*
c*Federally* funded R&D centers.
dForeign Citizens, organizations, governments, or international organizations, such as NATO, UNESCO, WHO, performing work abroad financed by the Federal Government.

SOURCE: "Federal Funds for Research and Development, Fiscal Years 1982, 1983, 1984, " vol. XXXII, Detailed Statistical Tables NSF 83-319, p. 30

universities and colleges.[8] Data collected by the National Science Foundation (see tables 2 and 3) indicate that Federal obligations for basic research in fields related to information technology included $103.7 million for computer science and $115.4 million for electrical engineering in fiscal year 1984. For applied research, funding levels are $145.8 million for computer science and $568.3 million for electrical engineering. These categories alone amount to $933 million in basic and applied R&D funding. In addition, there are other R&D areas related to information technology —e.g., mathematics, physics, and materials sciences.

[8] National Science Foundation, Early Release of Summary Statistics on Academic Science/Engineering Resources, Division of Science Resources Studies, December 1983. Also see *Federal R&D Funding The 1975-85 Decade,* National Science Foundation, March 1984, p. 11.

Table 2.—Federal Obligations for Basic Research in Information Technology-Related Fields (millions of dollars)

Year	Computer science	Electrical engineering	Total
1974	NA	$38.45	NA
1975		47.76	
1976	$26.59	53.08	$79.67
1977	31.02	55.14	86.16
1978	40.28	57.41	97.70
1979	42.96	62.03	104.98
1980	46.22	70,59	116.80
1981	52.21	78.51	130.71
1982	67.45	93.63	161.07
1983[a], ...	80.25	91,89	172.14
1984[a].	$103.66	$115.38	$219.04

[a] National Science Foundation estimates

NA—Not available.

SOURCE: National Science Foundation, "Federal Funds for Research and Development, Detailed Historical Tables" Fiscal Years 1955-S4, " p 275

Table 3.—Federal Obligations for Applied Research in Information Technology-Related Fields (millions of dollars)

Year	Computer science	Electrical engineering	Total
1974	NA	$230.79	NA
1975		239.20	
1976	$46.99	244.61	$291.60
1977	58.34	327.59	385.93
1978	66.97	375.22	442.19
1979	63.31	355.84	418.15
1980	82.38	446.56	528.93
1981	69.32	478.17	547.48
1982	103.49	518.56	622.05
1983	121.18	525.75	646.92
1984[a], ...	$145.85	$568.33	$714.18

[a] National Science Foundation estimates.

NA—Not available

SOURCE: National Science Foundation, "Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1955-84, " p 327

The Department of Defense (DOD), which has the largest of the Federal agency R&D budgets, is becoming increasingly dependent on electronics and computer science. By 1985, those fields will absorb nearly 25 percent of the total DOD R&D spending.[9] Within DOD, the Defense Advanced Research Projects Agency (DARPA) has heavily funded efforts in artificial intelligence, microelectronics, networking and advanced computer architecture.

No other agency compares with DOD, which accounts for about 60 percent of the Federal R&D budget.[10] NSF, for example, accounts for about 3 percent of the Federal total, with a fiscal year 1983 appropriations of just over $1 billion[11] and $1.32 billion and $1.5 billion in fiscal years 1984 and 1985 respectively.[12] NSF funding, which is heavily weighted toward the "basic" end of the R&D scale, supports research through grants, scholarships, university laboratory modernization, the establishment of university-based "centers of excellence, " and similar programs. Many of the information technology-related disciplines are funded through NSF programs: communications, electrical engineering, optoelectronics, mathematics, physics, materials research, information sciences, and so on. These information technology-related fields accounted for over $90 million in fiscal year 1984.

Since 1972, NSF has been the primary Government force in creating university-industry cooperative research centers, providing some of their startup funds, planning grants, and advice during their first years of opera-

[9] Cited in a speech by Dr. Leo Young, Office of the Under Secretary of Defense for Research and Engineering, DOD, at the IEEE 1984 Conference on U.S. Technology Policy, Feb. 22, 1984, Washington, DC.

[10] *Probable Levels of R&D Expenditures in 1984,* op. cit.

[11] *"Federal Funds for Research and Development, Fiscal Years, 1981, 1982, and 1983,* op. cit., p. 25.

[12] *Fiscal Year 1985* National Science Foundation Budget Estimate to Congress.

tion. The centers are expected to become self-supporting.[13] By the end of fiscal year 1984, NSF was involved with 20 of these centers and expects to make awards to at least 10 new centers in 1985.

A number of the centers are involved with information technology-related research. For example:

- Rensselaer Polytechnic Institute's Center for Interactive Computer Graphics is doing applied research in computer-aided design (CAD).
- North Carolina State University's Communications and Signal Processing Laboratory is primarily engaged in basic research.
- Both basic and applied research is being performed at the University of Rhode Island's Robotics Center.
- Ohio State University is doing basic and applied research in robotic welding.
- Georgia Institute of Technology's Center for Material Handling is engaged in applied research.

The National Science Board has recommended broadened NSF support for engineering research, an area long neglected in favor of the agency's traditional emphasis on basic scientific research. Congress approved about $150 million for NSF grants for engineering research in fiscal 1985, about 10 percent of the agency's total research budget.[14] The President's budget request for fiscal year 1985 calls for more funding for this purpose, as well as for establishment of cross-disciplinary engineering centers at universities which would, among other effects, promote research on computers and manufacturing processes.[15] Government funding of engineering equipment and facilities at universities decreased from $42 million to $17 million per year between 1974 and 1981,[16] but has been rising since then.

[13]DOD is also supporting this program through an $8 million grant, primarily for laboratory equipment.

[14]"National Science Foundation Starts to Broaden Support of Engineering Research," *The Chronicle of Higher Education*, Jan. 18, 1984, p. 17, and interviews with NSF officials, January 1985.

[15]Ibid.

[16]*Probable Levels of R&D Expenditures in 1984*, op. cit.

The Pattern of Government Funding of R&D in Information Technology

The Federal Government has had a long history of funding R&D in information technology-related fields. It is currently the major sponsor of those types of information technology R&D in which it has special interests. These include artificial intelligence, supercomputers, software engineering, and very large scale integrated circuits (VLSI), all areas in their technological infancy and with enormous potential for military as well as commercial applications. There is a long list of related technologies that have been stimulated by Government-often defense or other mission agencies —sponsorship of R&D including radar, guidance systems, satellite communications, and many others.

There are some historic examples of intensive Government sponsorship of technological development in areas where the potential benefit was expected to be great, but the risks and costs of research were high and therefore unattractive to industry —e.g., computers, aviation and communications satellites. One of the classic illustrations of a successful, major Government contribution to information technology R&D is in the field of satellite communications. The National Aeronautics and Space Administration (NASA) (which currently accounts for about 7 percent of the Federal R&D budget) had the leading role in pioneering technological progress toward commercial development, accelerating the time frame for the introduction of this technology, influencing the structure of the U.S. domestic and international telecommunications common carrier industries, and effecting significant cost savings over the long run.[17]

In these cases, the Government, through the undertaking of a number of risky and expensive R&D programs and with extensive private sector involvement, developed a large pool of baseline technology that served to prove the feasibility of geostationary satellite

[17]Morris Teubal and Edward Steinmuller, *Government Policy, Innovation and Economic Growth: Lessons From a Study of Satellite Communications*, Research Policy 11 (1982) 27-287, North Holland Publishing Co.

communications. These R&D programs were for the purposes of proving the feasibility of various technological advances such as geostationary orbiting satellites, electromagnetic propagation of signals from outer space, traveling wave tubes, automatic station keeping, and aircraft communications. The NASA programs initiated to undertake the extensive R&D included the SCORE, ECHO, and RELAY programs, the SYNCOM series of launches that paved the way for Intelsat I, the first commercial communications satellite, and the Applications Technology Satellites series. The costs for the RELAY, ECHO, and SYNCOM Programs alone through 1965 were over $128 million-an amount that few companies could–or would—commit, particularly considering that the feasibility of synchronous satellite operation was seriously questioned.[18]

It is also interesting to note that these NASA programs likely had some important side-effects on the structure of the U.S. international satellite communications industry. Because AT&T was the only private company to have heavily invested its own funds for satellite communications R&D—with focus on the nonsynchronous TELSTAR system—it is likely that AT&T would have dominated the new international and domestic satellite communications services industry. Instead, the NASA programs, through continuous transfer of technology to, and close interaction with, commercial firms stimulated the competition that followed the 1972 Federal Communication Commission's decision allowing open entry into the domestic satellite communications services industry.

The market for the supply of satellite communications equipment was also open to competition due to the expertise gained by NASA contractors. In addition, the international satellite network that evolved is owned and operated by INTELSAT, an international consortium, with the U.S. portion owned and operated by COMSAT, a broadly based private/public corporation.

[18]Ibid., p. 277.

Other Federal Government Policies

The Federal Government has many other means for promoting (or suppressing) private sector R&D activities including antitrust policy, patent policy, tax credits, technology transfer from Federal laboratories and federally funded R&D centers, and the promotion of Research and Development Limited Partnerships (RDLP). Export controls, whether for national security or political purposes, serve as a negative influence in promoting private sector R&D. A major source of corporate funding for R&D, international sales, is lessened, and the open exchange of technical data is limited. Six policies intended to promote private sector R&D are reviewed below.

PATENT POLICY

Previous policies assigning Federal ownership of patents based on Government-funded R&D have been modified in recent years with the intent to stimulate patenting and commercialization of invention. Public Law 96-517 (1980), which permits small businesses, not-for-profit institutions, and universities to obtain patents based on Government-sponsored R&D, is intended to encourage university-industry collaboration and patenting. The Government's right to patent ownership was further reduced by Presidential Memorandum (February 1983). This memorandum modified the Federal Acquisition Regulations by extending the concepts of the current law to allow all Government contractors to retain patent rights.

There are obvious tensions in this situation, since it is sometimes argued that the public should own patents derived from research it has funded. The counter-argument is that Government-owned patents tend not to become commercialized and the public reaps no real benefit from them. For example, Federal efforts to license its patents have resulted in a meager 4 percent being licensed, in contrast with 33 percent for university-owned patents.[19]

[19]Lansing Felker, U.S. Department of Commerce, Office of Productivity, Technology, and Innovation, during interviews with OTA staff, January 1984.

Allowing universities and businesses to retain ownership stimulates commercialization, but may also have the effect of distorting the university's traditional role as a developer of fundamental knowledge.

TECHNOLOGY TRANSFER

The Stevenson-Wydler Technology Innovation Act of 1980[20] was an attempt "to improve the economic, environmental, and social well-being of the United States," through such means as: establishing organizations in the executive branch to study and stimulate technology; promoting technology development through the establishment of centers for industrial technology; stimulating improved utilization of federally funded technology development by State and local governments and the private sector; and by other activities.[21] The act has been selectively implemented. Most of the Federal Laboratories have established Offices of Research and Technology Applications (ORTAs) which collect and disseminate the results of their respective Laboratory's research. The Center for the Utilization of Federal Technology, in the National Technical Information Service of the Department of Commerce, serves as a central clearinghouse.

However, the heart of the act, the Cooperative Generic Technology Program, has never been implemented. In February 1984, the Secretary of Commerce issued the first report to the President and the Congress on the progress of Federal activities conducted pursuant to the Act.[22] It appears that much of the work cited in the Report as "Stevenson-Wydler" activities would have been performed even if the act had not existed. For instance, the new patent policies discussed above and the R&D Limited Partnership (RDLP) discussed below were both cited as "Stevenson-Wydler' initiatives.[23]

'Public Law 96-480.

"For more details see the Stevenson-Wydler Technology Innovation Act of 1980, Report to the President and the Congress from the Secretary of Commerce. February 1984.

"Ibid.

"Ibid., p. 4.

The Act has probably had an effect on the activities of the Federal Laboratory Consortium (FLC). In 1984, the FLC established an award for excellence in technology transfer and issued 26 such awards. The Federal Laboratories, however, are mission-oriented; and no Federal Laboratory has a mission emphasizing the development of commercial technologies.[24] Thus, the concept of cooperative generic research laboratories envisioned by the Act has not been tested.

TAX CREDITS

Tax credits for businesses performing R&D have been expanded through the Economic Recovery Tax Act (ERTA) of 1981, which will expire in 1986 unless extended.[25] A key provision of ERTA allows companies to claim 25 percent tax credits for their qualified R&D costs above their average expenditures for the prior 3-year period. The law also allows for increased deductions for manufacturer's donations of new R&D equipment to universities, and provides a new capital cost recovery system for R&D equipment (modified later by the Tax Equity and Fiscal Responsibility Act of 1982–TEFRA).

Opinion is mixed as to whether this tax credit is effective in stimulating R&D investment. One study,[26] based on the limited available data, observes that the tax credit may well be helpful in encouraging increased R&D budgets. However, a current study finds very little effect on increased R&D spending due to the tax credit.[27] Battelle Memorial Institute attributes at least part of the increased industry investment in R&D to the tax credits.[28]

[24]OTA Memorandum, "Development and Diffusion of Commercial Technologies: Does the Federal Government Need to Redefine Its Role?" March 1984, p. 26.

[25]Public Law 97-34, August 1981.

'Eileen L. Collins, *An Early Assessment of Thins R&D Incentives Provided by the Economic Recovery Tax Act of 1981*, National Science Foundation, PRA Report 8307, April 1983.

"preliminary findings of an ongoing study by Edwin Mansfield, financed by the National Science Foundation.

[28]*Probable Levels of R&D Expenditures in 1984*, pp. 2, 11-12, op. cit.

R&D LIMITED PARTNERSHIPS

The Department of Commerce has been prometing wider use of R&D Limited Partnerships (RDLPs), and offers advisory assistance to businesses in their use. RDLPs are intended to attract venture capital to commercial R&D by limiting the potential losses to the venture capitalists while still permitting them to retain patent rights, if any, and to have prospects for receiving royalties or a subsequent buy-out by the company. RDLPs are sometimes used for conducting R&D with relatively short-term payoffs—e.g., 3 to 4 years. The use of RDLPs primarily affects the segments of the innovation sequence from prototype through product development.

During 1982, $275 million is estimated to have been invested in RDLPs, mainly through large brokerage houses. In 1983, the amount is estimated at $490 million; in 1984, it was $220 million.[29] Although these investments have tended to go for biotechnology, some have been allocated to information technology projects in fields such as computers, software, microelectronics, telecommunications, robotics, and artificial intelligence. The drop in funding in 1984 is believed by investment bankers to be due to two trends. First, there is a general drop in investor interest in high technology. Second, some investors appear to be concerned about possible changes in tax laws that may give less favorable treatment of R&D tax deductions and capital gains.

ANTITRUST POLICY

There have been administrative proposals and congressional bills that would limit the use of the treble damage penalty against companies found guilty of antitrust violations and establish clearer guidelines for companies considering cooperative research activities.

There have been arguments noting that the antitrust laws have not had a chilling effect on cooperative research since they are rarely used. However, until recently businesses have been exceptionally cautious about such ventures because of concern over litigation.

Some of the questions that arise in considering more liberalized interpretation of antitrust legislation concerning joint research are:

- Will U.S. companies, long accustomed to performing much of their R&D individually, be able to adapt swiftly to a different mode of operation? What will be the real commitment to shared research? How will intellectual property issues be resolved?
- Will there be new opportunities for collusion among joint R&D partners that recreate historical antitrust problems?
- Will joint R&D dilute the benefits of competition even in basic research? Will small firms be disadvantaged?

in the closing days of the 98th Congress, the National Cooperative Research Act of 1984 was passed. The Act eliminates the treble damage penalties in antitrust cases involving joint R&D ventures when those ventures meet the conditions of the Act, in particular, by providing prior notification to the Federal Trade Commission and the Justice Department.

INDUSTRIAL POLICY

An important topic debated in Congress concerns industrial policy and the appropriate role of Government in strengthening industry. One approach would provide an environment generally conducive to industry reinvestment, productivity improvements, and increased competitiveness through tax, antitrust, patent, and other policies. A different approach would assist selected industries, create a high-level industry-labor-Government advisory council, and provide loans and loan guarantees.

Among the issues that surround the debates are whether the Government could be effective in selecting industries for support; whether businesses, without further encouragement, would invest their resources in areas most beneficial to the Nation's competitiveness; and whether foreign national industrial policies pose insuperable problems for U.S. businesses.

[29] Data based on interviews by OTA staff with officials from the Office of Productivity, Technology, and Innovation, U.S. Department of Commerce, and key sources in the investment banking community, Jan. 29, 1985.

There may also be important lessons from the various foreign experiences with targeted industrial policies, many of which may not be suitable as models for the United States (see *Ch. 7: Foreign Information Technology R&D).*

Industrial R&D

The corporate motivation for performing R&D centers about the need to maintain or improve market share and profitability for both the short and long term. For high-technology businesses in general, R&D plays a critical–although not singular-role in helping the firm to sustain or improve its competitive position.

Funding and Licensing of Research

The information technology industry in the United States spent about $10.8 billion for R&D in 1983. As is typical of a high-technology industry, the firms in information technology often spend a large proportion of their sales revenue on R&D—for supercomputer manufacturers the ratio was nearly 20 percent in 1982, and it is believed to have been comparable in 1983. In 1983, overall R&D spending by computer manufacturers rose by 19.5 percent; spending by computer software and service vendors rose by 38.9 percent; and telecommunications R&D rose by 31 percent. The importance of R&D to these firms can be seen from the fact that even during the recent economic recession they continued to make substantial R&D investments.

While information technology companies perform much of their R&D in-house, they also make use of research originating in universities, other companies, and the Federal Government through licensing and other arrangements for technology transfer. Licensing and cross-licensing are often used as means of acquiring technology quickly and for recovering R&D expenses.

Protection of Research Results

Leadtimes in research and product development are very important for capturing markets, recovering R&D expenses, and contributing to profitability and further R&D investment. A 6-month leadtime in getting products into commercial markets can make the difference between market dominance and substantial losses. The information technology industry's significant investments in R&D, the high mobility of technical personnel, and the increasing internationalization of R&D, encourage rapid diffusion of technical data and frequent introduction of new products. These characteristics intensify the need for legal protection of new ideas and products.

Certain areas of information technology are especially vulnerable to "borrowing" and the degree of legal protection available is uncertain. Software, for instance, can be copywriter but cannot be patented except in certain instances. Policy is being made in the courts, virtually on a case-by-case basis, and the resultant ambiguities satisfy no one. The entire problem of intellectual property rights has become a matter for national attention.

Industry-University Links

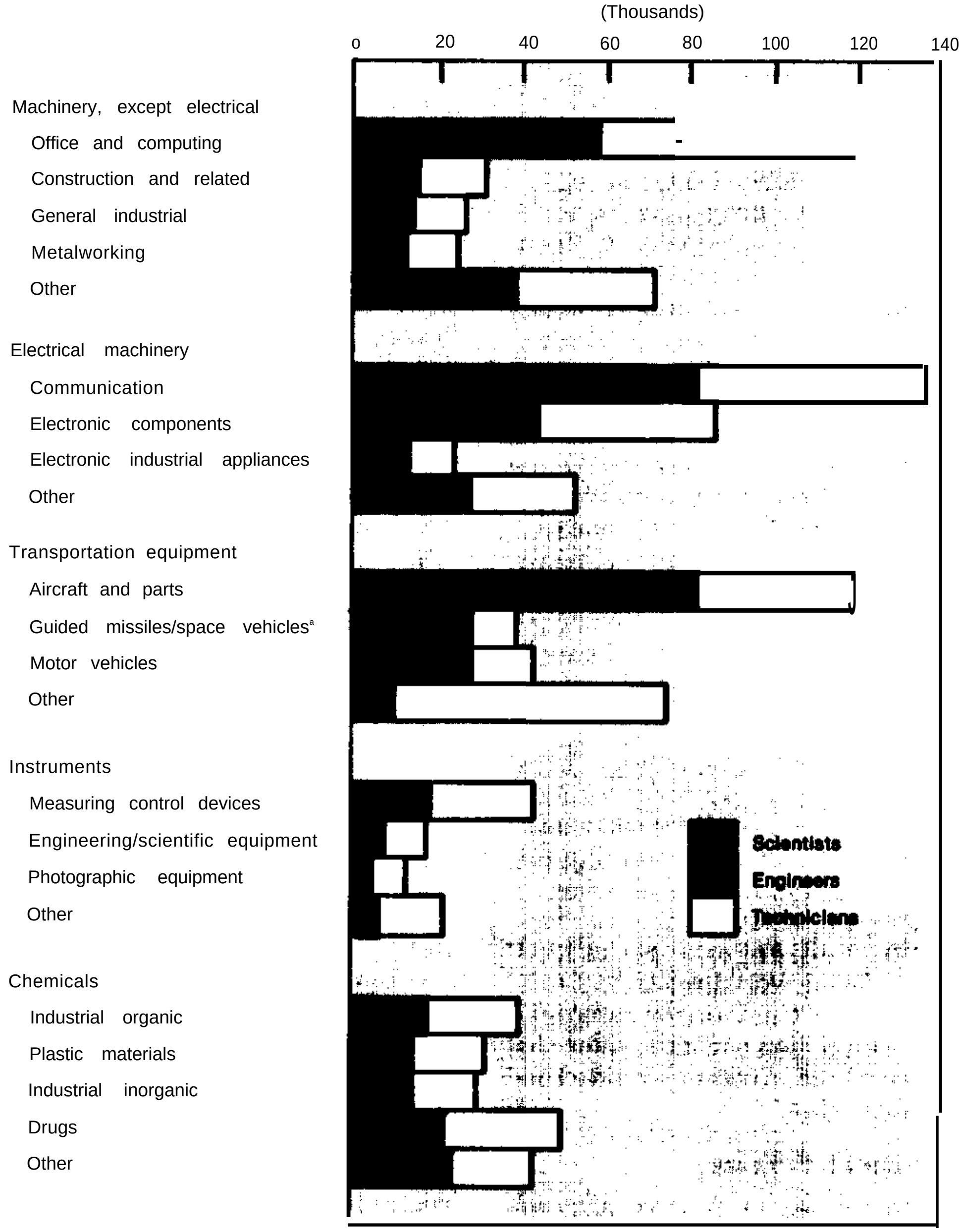
Chapter 6 of this report describes in detail the relationship of the information technology industry and the universities. International competition is causing U.S. industry to become increasingly sensitive to the importance of academia both as a performer of information technology-relevant basic research and as a supplier of trained personnel.

The information technology industry is a major "consumer" of technically trained personnel. As shown in figure 2, the office/computing and communications industries are rivaled only by the aircraft and parts industry in terms of overall employment of scientists, engineers, and technicians. According to statistics compiled by the National Center for Education Statistics,[30] some 21,400 electrical, electronic, and communications engineering and 25,500 computer and information science majors graduated in 1982. Within those disciplines, less than 2 percent are unemployed.[31] There is some controversy surrounding the putative shortage of future manpower for information technology research (discussed at

[30]National Center for Education Statistics, Survey of Earned Degrees Conferred, reported to OTA by Dr. Vance Grant, Jan. 3, 1984.

[31]Congressional Budget Office, *Defense Spendeng and the Economy,* Table A-7, p. 59, February 1983.

Figure 2.—Science, Engineering, and Technician Employment Within High-Technology Industries, 1980



[a]Scientific employment was not reported because confidentiality rules and/or Statistical reliability prohibit data release

SOURCE: National Science Foundation, Changing Employment *Patterns of Scientists, Engineers, and Technicians in Manufacturing Industries, 1977-80* length inch. 7) but there is certainly no present oversupply of well-trained R&D personnel nor is there doubt that industry is dependent on the university system to produce the manpower necessary to maintain a sufficient level of R&D.

Industry is both influenced by, and influences, university training programs. In addition to its needs for traditionally trained graduates, there is a growing need for graduates with multidisciplinary training. For example, companies involved in fiber optic communications require researchers trained in both physics and electronics-a combination which is not part of traditional curricula. A similar situation applies in the "expert" systems field, where a wider range of skills are needed and broad scientific training is especially valued. These shifting industry needs place demands on universities to alter their curricula and to create multidisciplinary institutional structures, and they increasingly require frequent retraining of professional technical personnel.

In some cases, information technology firms requiring special skills not normally produced by academia have compensated for the shortfall by providing additional cross-training for employees, by helping selected universities to develop new curricula, or by furnishing supplemental teaching staff. For example, in 1983 IBM announced that it would make $10 million available to support university researchers and another $40 million earmarked for the development of curricula in computer-aided design and manufacturing.

Foreign Government Policies

Policies and practices of foreign governments and companies can influence the profitability of U.S. companies or deny them markets, and thus effectively restrict their ability to invest in R&D. These policies and practices include pricing exports at below cost in order to capture larger market share and the advantage of scale, targeting specific advanced technology markets through government-sponsored industrial strategies, creating nontariff barriers (e.g., discriminatory certification practices), restrictions on foreign direct investments, exclusion of U.S. subsidiaries from R&D programs funded by the host government, preferential treatment of domestic producers in government procurement, and export credits.[32]

Jointly Funded Research

Recently, the industry has made what may be the beginning of a major shift from its traditional pattern of conducting independent R&D, toward undertaking some joint or cooperative efforts. There are a number of examples in which companies are jointly supporting basic and some applied research through newly formed cooperative organizations, which rely heavily on university and corporate researchers. Among these new organizations are the Microelectronics Center of North Carolina, the Semiconductor Research Corp., and the Microelectronics and Computer Technology Corp. A detailed discussion of these arrangements and the policy issues arising from them is contained in chapter 6.

These cooperative research efforts were spurred by escalating R&D costs, by a perceived limited supply of science and engineering talent, and by the apparent erosion of information technology industry's international competitive position. Some leaders in the industry argue that it has neither the resources nor the time to continue its established pattern of across-the-board duplicative R&D. This does not mean that information technology companies intend to slacken their competitive R&D work vis-a-vis proprietary technologies. If anything, the cooperative projects are expected to lead to more innovation and more competition at the level of the participating companies.

Cooperative research programs require a careful distinction between proprietary and nonproprietary technology. Nonproprietary technology is made up of:

- generic technology, consisting of scientific and engineering principles that form

[32] For more details, see *International Competition in Advanced Technology: Decisions for America,* op. cit., pp. 28-37.

a competitively neutral technology base that can be shared by all firms without reducing the potential benefits for any one firm; and
- infratechnology, consisting of the knowledge base necessary to implement product and process design concepts. It includes such things as basic data characterizing materials, test methods, and standards. Like generic technology, the infratechnology is competitively neutral.

The various cooperative arrangements are concerned with the nonproprietary technologies.

Cooperative Government-industry development of nonproprietary technical standards is a related area important to industry. A recent example is the cooperative effort of the National Bureau of Standard's Institute for Computer Sciences and Technology (ICST) and 12 information technology firms in developing and demonstrating networking technology for office systems. A similar cooperative project is aimed at developing networking technology for the factory floor. These efforts are based on the development of nonproprietary standards. The programs, which began joint demonstrations in 1984, permit the products of different manufacturers to work together compatibly and therefore expand the market for them.

In the long term, continued expansion of U.S. cooperative research activities could have policy implications for the appropriate amounts and focus of Federal funds for R&D, for universities' needs for outside support, and for invigorating segments of the university research environment—and the potential for altering the status of U.S. R&D relative to other nations.

Universities' Role in R&D

The exceptionally broad nature of the underpinnings of information technology, and the escalating complexity associated with continued advances based on research, indicate an increasing role for universities. Major advances in fundamental knowledge are often the result of decades of dedicated and expensive research-efforts which few commercial firms would be willing to undertake. In each of the four areas of information technologies selected for the chapter 3 case studies (advanced computer architecture, fiber optics, software engineering, and artificial intelligence), universities have made and are continuing to make valuable research contributions in technologies that the private sector commercializes.

The intensity and breadth of university research is dependent on a wide variety of factors, ranging from the prestige of the institution, graduate enrollment, ability to retain qualified faculty and researchers, adequacy of funding for researchers, adequacy of facilities and laboratory equipment, affiliations with major companies, and increasingly on interactions with other researchers domestically and internationally. It is also dependent on a large proportion of foreign graduate students– as many as 50 percent in some universities-particularly in disciplines such as engineering.

The intensity of university R&D is also dependent on the level of funding for research provided by the Federal and State governments, as well as by industry. About 85 percent of the funding for university and college R&D came from external sources.[33] Federal and State governments as well as industry provide funding for research, for scholarships, for laboratory equipment, and for real estate. The universities accounted for about one-half of all basic research expenditures in 1984, with 70 percent of their funding provided by the Federal Government.

Laboratory Research Instrumentation and Facilities

During the past few years, problems concerning the obsolescence of university laboratory research instrumentation and facilities, and a lack of access to supercomputer equipment, have been recognized in many academic disciplines. This problem is not specific to in-

[33] National Science Foundation, *Early Release of Summary Statistics, etc.*, table 1, December 1983.

formation technology, but this field is among those affected. A decline in university research capabilities could result in a significant decline in the overall rate of the Nation's scientific advance.

One study notes that when the appropriate instrumentation needed to conduct specific research is unavailable, then research objectives are altered to match that which is available.[34] This source also reports that leaders within the scientific community have estimated the cost of updating university research equipment to lie between $1 billion and $4 billion. In particular, instrumentation with costs between $100,000 and $1 million at U.S. research universities is reported as becoming obsolete.[35] One estimate stated that selected instrument costs have increased fourfold since 1970.[36]

Compounding the problem is the fact that the most up-to-date research equipment has a short lifetime-only 3 to 8 years.[37] Another study which compared university laboratory equipment with that of industrial laboratories found that the median age of university laboratory equipment was twice that of the equipment found in the laboratories of companies performing high-quality research.[38]

The same study also noted that until recently, not a single top-line supercomputer was installed in service at a U.S. university. A number of foreign universities, however, are equipped with supercomputers.[39] In part as a response, the Federal Government is increasingly sharing its supercomputers with its contractors, many of which are universities. During fiscal year 1984, $6 million was authorized for NSF to buy access to the equivalent of one supercomputer for scientific use. This amount was increased to $40 million in fiscal year 1985 and will contribute to the establishment of six or seven supercomputing centers nationwide over the next 5 years. In addition, four U.S. universities have recently acquired supercomputers.

Further acquisitions of supercomputers by universities may be curtailed both by financial limitations and by the difficulty of assembling the expert staff needed to maintain the facilities. Consequences of obsolescence are likely to include foregone opportunities to perform frontier university research, less-than-optimal training for graduate students, a continuation of the migration of faculty and new graduates to industrial laboratories, and a deterioration in the quality of U.S. instrumentation, because university researchers traditionally provide valuable feedback and innovative improvements to the instrument manufacturing community.

A number of factors have contributed to the obsolescence of university laboratory equipment. Among these are the long-term decrease in Federal funding for R&D plant in universities and colleges since 1965[40] (fig. 3); an approximately four- to six-fold increase between 1970-80 in the costs of state-of-the-art instru-

[34] Testimony of Charles A. Bowsher, Comptroller General, GAO, before the Senate Committee on Commerce, Science, and Transportation, Subcommittee on Science, Technology, and Space, Research Instrumentation Needs of Universities, May 27, 1982.

[35] *Obsolescence of Scientific Instrumentation in Research Universities*, Emerging Issues in Science and Technology, 1981, A Compendium of Working Papers for the National Science Foundation, National Science Board, p. 49.

[36] *Science*, vol. 204 (1979), p. 1365, as reported in *Obsolescence of Scientific Instrumentation in Research Universities.*

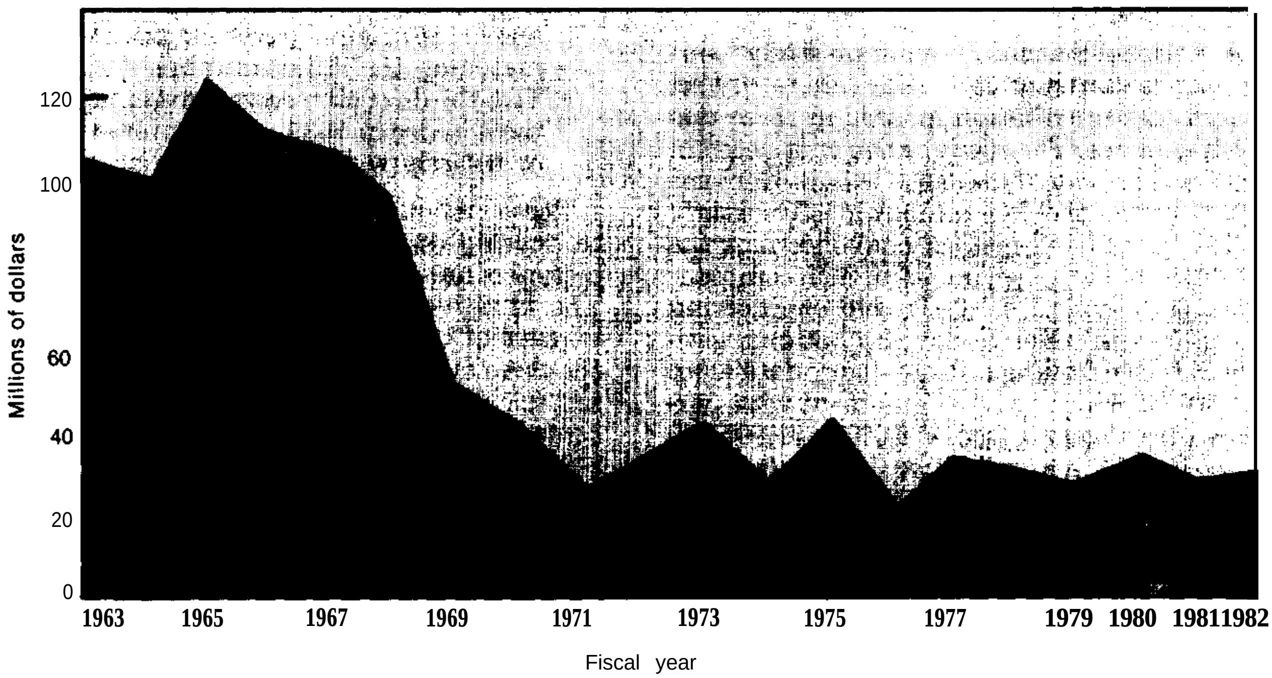
[37] *International Competition in Advanced Technology: Decisions for America*, op, cit., pp. 47-48.

[38] L. Berlowitz, R. A. Zdanis, J. C. Crowley, and J. C. Vaughn, "Instrumentation Needs of U.S. Universities," *Science*, vol. 211, Mar. 6, 1981, p. 1017, as reported in *Obsolescence of Scientific Instrumentation in Research Universities.*

[39] Among these are: West Germany's Max Planck Institute and the Universities of Karlsruhe, Stuttgart, Berlin, and KFA; Japan's Universities of Tokyo and Nagoya; England's Universities of London and Manchester; France's Ecole Polytechnique; and in Sweden, one-half time access by universities to a major auto manufacturer's supercomputer.

[40] "The Nation's Deteriorating University Research Facilities, A Survey of Recent Expenditures and Projected Needs in Fifteen Universities," prepared for the Committee on Science and Research of the Association of American Universities, July 1981, p. 4. This survey covered 15 leading universities and six academic disciplines.

Figure 3.—Federal Obligations to Universities and Colleges for R&D Plant



SOURCE: National Science Foundation.

mentation[41]; and the short lifetime of state-of-the-art equipment and high maintenance costs. In addition, during periods of decreased funding, university laboratory administrators tend to forego instrumentation purchases rather than reduce project staffs.[42] Further, until recently, Federal funding for research projects did not allow for purchase of instrumentation if it was to be shared with other projects.

Quantification of the Problem

Until recently, much of the information concerning the extent of the obsolescence problem has been anecdotal. However, there are now a number of initiatives to provide statistical data quantifying its scope and the effect on specific disciplines. In addition to the need for suitable data collection, there is a need to identify critical areas affected, the trends or rate of change, and likely influence of new initiatives to relieve the problems.

A GAO investigation into the instrumentation of obsolescence issue found "a tremendous lack of information": an absence of trend data on nationwide research equipment expenditures by universities, a lack of consensus on university laboratory needs, and no comprehensive indexes that would *measure* changes in the price of equipment[43 44] or the costs to maintain it. GAO also found that the rapidly increasing costs for instrumentation in conjunction with relatively level funding of basic research (in constant 1972 dollars) at universities and colleges for the period 1968-81 combined to have a "large effect on re-

[41] "Revitalizing Laboratory Instrumentation, The Report of a Workshop of the Ad Hoc Working Group on Scientific Instrumentation," National Research Council, March 1982, p. 1. This source estimates a sixfold increase in costs, while others estimate a fourfold increase.

[42] Testimony of Charles A. Bowsher, Comptroller General, GAO, op. cit.

[43] Ibid [GAO testimony].

[44] An illustration of cost escalation is the $100,000 premier electron microscope of the 1960s, which could distinguish objects smaller than one-millionth of a meter. By 1970, the scanning transmission electron microscopes had improved the resolution by a factor of 1,000, and cost more than $1 million. (Testimony of Dr. Edward A. Knapp, Director, NSF before the House Subcommittee on Science, Research, and Technology, Feb., 1984.)

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searchers' acquisition and maintenance of research equipment. "

A National Science Foundation study[45] surveyed the status of university laboratory research instrumentation in 1982 in three major disciplines. The study, when completed in 1985, will provide some useful insights into the extent of the problem nationwide. The study polled 43 academic institutions concerning the condition of their instrumentation in computer sciences, physical sciences, and engineering disciplines in order to develop national estimates of the findings. Preliminary data from the study, which covers equipment with purchase prices ranging from $10,000 to $1,000,000 in use in 1982, may not either confirm or refute the notion of a serious problem with instrumentation obsolescence in these three fields, but does seem to demonstrate that the problem may not be uniform. For example:

- University officials classified 26 percent of the research equipment listed in these fields in 1982 as "not in current use. " Some portion of this undoubtedly is obsolete. Seventeen percent of the laboratory equipment associated with computer science research was obsolete; 24 percent of the physical sciences and engineering equipment was obsolete.
- One-half of all of the academic research instruments in the fields surveyed that were still in use in 1982 were purchased during the 1978-82 period. Only 12 percent of the computer science instrumentation was purchased prior to 1972, and 78 percent was purchased during 1978-82.
- Concerning state of-the-art equipment, 98 percent of the computer science equipment in this category had been acquired since 1978, compared with 80 percent of the engineering research equipment. Eighty-four percent of all of the state-of-the-art equipment surveyed was listed as in excellent condition, as compared with 42 percent of all equipment covered by the survey.
- The replacement value of all instrumentation in use was estimated at 42 percent above the original purchase price (almost matching the inflation rate).
- Two-thirds of all research instrument systems in use in 1982 were acquired partly or entirely with Federal funds.

These preliminary findings indicate the need to develop data providing a comprehensive picture of university research instrumentation. The 43 universities surveyed account for 94 percent of the R&D expenditures in each of the three disciplines (computer sciences, physical sciences, engineering) covered and had instrumentation inventories that cost nearly $1 billion-a significant portion of which was funded by the Federal Government. Exactly how much total funding is needed to equip the laboratories adequately is not known. However, it is possible to make some very approximate, inferential estimates based on the available data. For example: given an instrument inventory of $1 billion and assuming that the equipment has a 4-year lifespan, one-quarter of the equipment ($250 million current dollars) would be needed annually to upgrade the equipment assigned to those three disciplines in the 43 universities.

Remedial Activities

Federal agencies, State governments, and industry have begun to address the instrumentation problem. For example, the Department of Defense initiated a $150 million 5-year program in fiscal year 1983 to fund instrumentation in areas of research in support of its mission. DOD's University Research Instrumentation Program is based in part on a 1980 study[46] of the instrumentation needs of U.S. university laboratories to conduct defense-related research. The pervasiveness of the problem is illustrated by the estimated 2,500 responses from the academic research community to an initial DOD invitation for proposals for funding.

[45]"One Fourth of Academic Research Equipment Classified Obsolete, " Science Resources Studies Highlights, NSF, 1984.

[46]American Association of Universities Report to the National Science Foundation, Scientific Instrumentation Needs of Research Universities, June 1980. See also Berlowitz, et. al., op. cit.

In addition, NSF's appropriation increased from $195 million in fiscal year 1984 to about $234 million in fiscal year 1985 for support of advanced instrumentation. Some $122 million in fiscal year 1985 (up from $104 million in fiscal year 1984) will be allocated to research instrumentation for individual project grants, and the remainder for instrumentation for multi-user regional instrumentation centers and major equipment in national centers.

The universities are also concerned about obsolete or inadequate research facilities, or buildings–which Federal agencies have not funded since the 1960s. One preliminary estimate of the funds needed to fully upgrade facilities at the Nation's major research universities is between $990 million and $1.3 billion per year.[47] NSF is leading the interagency Steering Committee on Academic Research Facilities (which includes representation from DOD, DOE, the National Institutes of Health, and U.S. Department of Agriculture) to address this issue. The committee is expected to recommend that a study be initiated to clarif y requirements for additional buildings or modernization programs for the Nation's academic research institutions. In addition, the National Science Board addressed this issue during its June 1984 session and recommended that funding for facilities become a component of the fiscal year 1986 NSF budget. It recommended that NSF conduct pilot programs for R&D facilities construction in three areas of priority research (large-scale computing, engineering research centers, and biotechnology), and that NSF support the Committee by obtaining improved data on the condition of university facilities. The House Authorization bill for the fiscal year 1984 budget of the Department of Defense directed that agency to determine the need to modernize university science and engineering laboratories for national security purposes. Congress has requested NIH to make a similar determination with respect to its mission.

State Government and Industry Initiatives

Among the various State government initiatives to improve university research capabilities are those of North Carolina, Massachusetts, New York, California, and Minnesota (see ch. 6).

Industry is also contributing at a significant level to academic information technology research and education. For example, seven computer vendors alone have made recent commitments to contribute some $180 million in cash and equipment to universities. One source "conservatively" estimates the level of donations of computer equipment to higher institutions of education to exceed $100 million in 1982. Among the major contributors were IBM, Digital Equipment Corp., Apple Computer, Inc., Hewlett-Packard Co., Wang Laboratories, Inc., NCR Corp., and Honeywell, Inc.

Two other recent examples further illustrate the trend: Brown University built a $1.5 million computer science facility based on contributions from IBM, Xerox Corp., Gould, Inc., and others; the University of California at Berkeley has commitments of $18 million in cash and equipment from firms such as Fairchild Camera & Instrument Corp., Advanced Micro Devices, Bell Laboratories, Digital Equipment Corp., GE, Harris, Hewlett-Packard, Hughes Aircraft, IBM, Intel, National Semiconductor, Semiconductor Research Corp., Tektronix, Texas Instruments, and Xerox.[48]

Changing University Role

The role of university research maybe at the threshold of significant change. Faced with the increasing expense and risks associated with research, a limited supply of trained personnel (especially in needed multidisciplinary skills), and intensifying competition, U.S. industry is taking steps to bolster the universities' role in the performance of research in information

[47] Adequacy of Academic Research Facilities, A Brief Report of a Survey of Recent Expenditures and Projected Needs in Twenty-Five Academic Institutions, National Science Foundation, April 1984.

[48] These donations are seen as motivated by business strategies, and to some extent, by the 1981 changes in the Federal tax regulations which provide tax advantages for donations of new equipment to schools.

technology. State governments are promoting their universities' research capabilities to attract technology-intensive industry.

The National Science Foundation's support of engineering research at universities is also contributing to the change. With a $150 million appropriation for fiscal year 1985, NSF will increase the range of engineering projects supported and will help to establish more university engineering centers to promote research on computers, manufacturing processes,[49] and other nationally important technologies. Many of these joint activities are emphasizing strengthened linkages among the ties, promoting entrepreneurship, and improving the overall scientific and technological base of State and local communities.[60] They are also serving to add to both the supply and the quality of degreed professionals, and to modernize the tools available in participating university laboratories.

The universities may find themselves in a position in which they are looked to as critical to U.S. competitiveness in domestic and world markets, to our ability to maintain technological prominence and to remain reasonably self-sufficient in critical areas for national security purposes. Undoubtedly, for these and other reasons—such as the growing need for life-long education for many professionals–there will be forces for change in the role of universities.

Conflicts in Perspectives, Goals, and Policies

These various participants-academia, industry, and Federal and State governments–work together in a sort of dynamic balance, despite some differing perspectives among participants, and some discords in goals and policies. For example:

1. National economic goals for improving productivity and competitiveness in international markets are supportive of a healthy information technology industry. However, productivity improvements are viewed by some as possibly resulting in fewer employment opportunities, and lower job skill requirements and pay levels.
2. National science endeavors are fostered by measures that increase fundamental knowledge, consistent with university and scientists' objectives-including the sharing of research results internationally—but may be contrary to national security objectives of controlling technology transfer and industry concerns for protecting research data.
3. Universities' and scientists' interests in conducting undirected (basic) research may be in conflict with industry's and mission agencies' need for achieving specific results. The current trend toward increased university-industry collaboration and toward university patenting may result in more directed university research and less independence of universities.
4. U.S. policies toward opening university admission to foreign students have been enormously successful, but other regulations encourage emigration of aliens after graduation, thus depriving U.S. firms and academic institutions of needed talent.

The most striking observation concerning the roles of the various participants is that they are in a state of flux. To date, the directions of the changes appear to be: 1) modified interrelations among the participants in the R&D process, 2) a significantly larger role in research for participating universities, and 3) a potential strengthening of national capabilities to conduct R&D in information technology.

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[49] National Science Foundation starts to broaden suPPort of engineering research, *The Chronicle of Higher Education*, Jan. 18, 1984, p. 17, and updated by NSF officials, January 1985.

[60] For more detailed information, see Technology, Innovation, and Regional Economic Development, Background Paper No. 2, Encouraging High Technology Development, Office of Technology Assessment, February 1984.

Measures of the Health of U.S. R&D in Information Technology

There is no single indicator of the health of R&D in information technology. However, a combination of indirect indicators can provide an impression of its overall vigor in the United States. Indicators of industry growth include the level of funding for R&D, the availability of trained personnel, trade balances for information technology exports and imports, and patent trends. Although the indicators used are not comprehensive, taken together they portray a robust industry with significant growth in sales and investment in R&D. They also show that these industries account for the employment of a high proportion of the Nation's technically trained work force as well as a substantial proportion of its industry- and government-funded R&D. Paradoxically, they provide a varying contribution to the U.S. trade balance, and a declining proportion of the total number of information technology patents granted in the United States.

These indicators, while generally promising in themselves, provide far less than a complete picture of the state of health of U.S. R&D in the information technology industry. International competition in both information technology markets and in R&D is intensifying and U.S. leadership in many of these areas is being seriously challenged. Also, as described previously, aspects of the R&D process are in flux and it is too early to tell whether the changes are for better or for worse. In addition, while this report focuses on information technology R&D, several other factors play critical roles in U.S. competitiveness. These include marketing strategies, manufacturing capabilities, and global macroeconomic and trade conditions.

Beyond that, as noted earlier in this chapter, the "information technology industry" is an ill-defined entity and the available statistics are often noncomparable. Much of our information is based on statistics pertaining to a small subset of the Standard Industrial Code (SIC) for manufacturing companies without accounting for the significant revenues from services. One statistical comparison will serve to illustrate the problem of noncomparability: In 1982, shipments of all electronic computing equipment establishments totaled $34.1 billion; in the same year, data processing revenues of the top 100 information technology companies totaled $79.4 billion.[51]

Because of these data inconsistencies the information presented is skewed by the noncomparable databases; and, for that reason, quantifications can only be regarded as approximate.

Information Industry Profile

The review presented in chapter 9 of business statistics for the U.S. information technology industry indicates that this industry is generally robust as measured in a variety of ways, and in comparison with U.S. industry as a whole. For example, for the 1978-82 period: sales revenue grew by 66 percent compared with 40 percent for the composite U.S. industry; profits grew by 36 percent compared with 6 percent for the composite. Profits-to-sales ratios were about 9 percent v. 5 percent; and the growth in the number of employees averaged 12 percent v. a negative 8 percent.[52]

Concerning R&D, the information technology industry is also vigorous. R&D expenditures compare very favorably to the composite industry when measured as a percentage increase over the period, as a percentage of sales, or in terms of R&D expenditures per employee. This industry accounted for 28 percent of the total R&D spending by all industries.

[51] Based on a draft report, *The Computer Industry and International Trade: A Summary of the U.S. Role*, by Robert G. Atkins, Information Processes Group, Institute for Computer Sciences and Technology, 1984.

[52] These data primarily represent large firms. See table 52 (ch. 9) for limitations.

In fact, a listing of the 15 U.S. companies that spend the most on R&D—as a percentage of sales, and in dollars spent per employee-is almost completely populated with information technology companies such as Cray Research, Telesciences, Advanced Micro Devices, LTX, Amdahl, Computer Consoles, and Convergent Technologies[53] (table 4).

The electrical and communications industry increased R&D budgets by approximately 13 percent in 1984 and 1985. These increases resulted in large part from R&D on semiconductors and telecommunications. During 1984 and 1985, electrical and electronics companies plan to accelerate their investment in communications R&D, including work on integrated power semiconductors and cellular radio." Thus, the industry viewed broadly is committed to well-funded R&D.

Comparison of R&D Funding by Selected Countries

Funding levels for R&D are generally recognized as important to the innovation process, as noted earlier. The United States has fallen behind two of its major competitors, as measured in terms of total outlays for R&D as a percentage of Gross National Product (excluding expenditures for defense and space) .66 Figure 4 shows that both Japan and West Germany have been outpacing the United States (as well as France and the United Kingdom) by this measure for more than a decade. Both of these countries have relatively small R&D expenditures for defense and space purposes as a percentage of GNP—e.g., 2.5 and 5.6 percent in 1981 for Japan and West Germany, respectively, in contrast with 31 percent for the United States, 29 percent for France, and 30 percent (in 1975) for the United Kingdom.

The Influence of DOD Funding of R&D in Information Technology

DOD funding for R&D in information technology reflects its growing dependence on this technology and its reluctance to be dependent on foreign sources for technology critical to national security. Defense spending for R&D generally has ranged from a high of 90 percent of Federal R&D spending in 1953 to a low of 50 percent during 1976-80, and is expected to rise to 70 percent in 1985.[56]

Table 5 shows the distribution of DOD funding for 1983 among basic and applied research,

[53] *Business Week*, R&D Scoreboard 1982, June 20, 1983, pp. 122-153.

"Science Resource Studies, Highlights, National Science Foundation, NSF 83-327, Dec. 15, 1983, p. 2, and NSF 84-329, Oct. 15. 1984.

[55] See William C. Boesman, U.S. Civilian and Defense R&D Funding: Some Trends and Comparisons with Selected Industrialized Nations, Congressional Research Service, Library of Congress, Aug. 26, 1983.

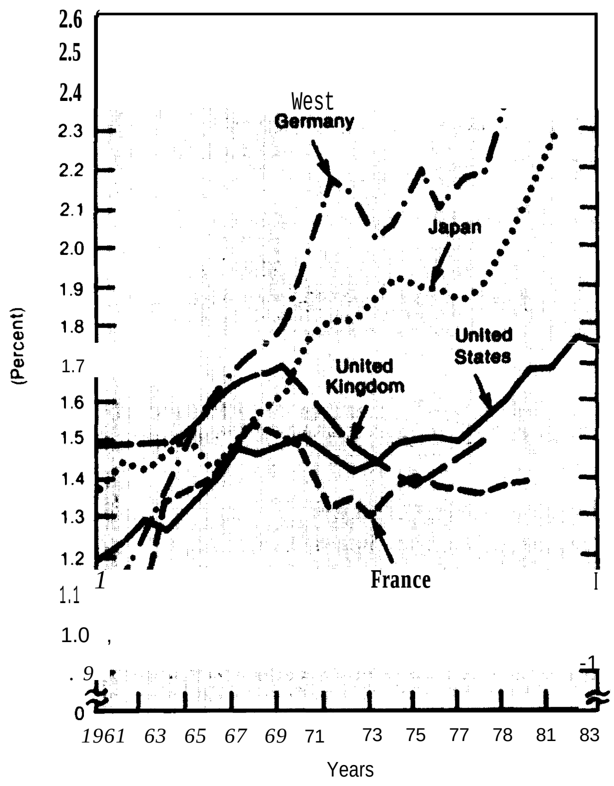
[56] Ibid.

Table 4.—The Top 15 in R&D Spending

In percent of sales		In dollars per employee	
1. TeleSciences	31 .6°/0	1. Ultimate	$37,089
2. Policy Management Systems	26.6	2. Fortune Systems	19,390
3. Fortune Systems	22.3	3. TeleSciences	18,797
4. Management Science America	20.8	4. Convergent Technologies	18,721
5. King Radio	20.0	5. Activision	16,667
6. Dysan	19.4	6. Cray Research	16,467
7. Advanced Micro Devices	19.4	7. Management Science America	15,563
8. Modular Computer Systems	17.6	8. Amdahl	15,413
9. ISC Systems	16.6	9. Digital Switch	15,017
10. Computer Consoles	16.6	10. Policy Management Systems	14,677
11. LTX	16.4	11. Applied Materials	14,545
12. Ramtek	15.6	12. Auto-trol Technology	14,413
13. Applied Materials	15.6	13. Computer Consoles	13,816
14. Auto-trol Technology	15.4	14. Network Systems	13,292
15. Kulicke & Soffa Industries	15.3	15. LTX	13,229

SOURCE: Standard & Poor's Compustat, Inc., as cited in *Business Week,* "A Deepening Commitment to R& D," July 9, 1984, p. 64; and "The U.S. Still Leads the World in R&D Spending, " June 20, 1983, p 122

Figure 4.— Estimated Ratio of Civilian R&D Expenditures to Gross National Product for Selected Countries



and development. DOD spending for basic research accounts for some 13.6 percent of the total Federal obligations, while applied research accounts for 33.9 percent, and development accounts for 71.3 percent.

Table 6 shows that the DOD R&D budget dominates some fields of Government R&D spending for basic and applied research. For example, in funding for basic research in electrical engineering, DOD accounts for some 69 percent; in computer sciences, 55 percent; and in mathematics 42 percent. In applied research, the DOD is a major Federal funder for electrical engineering (90 percent), computer sciences (87 percent), and mathematics (29 percent). These, as well as others, are disciplines supported primarily by the DOD R&D budget and that have a central influence on advances in information technology for the Nation.[67]

There have been many commercially applicable advances in information technology that have their origin in, or had strong early support from, DOD funded R&D. These include very high speed integrated circuits (VHSIC), digital telecommunications, and new high-performance materials. However, there are some major disadvantages for the commercial sector to DOD funded R&D. Among these are: security classifications which tend to slow advancements in technology; rigid technical specifications for military procurements which have limited utility for commercial applications; and the "consumption" of limited, valuable scientific and engineering resources for military purposes, which may inhibit commercial developments. This issue is discussed in more detail in chapter 8.

U.S. Patent Activity

It is generally accepted that patenting is a measure, even if imperfect, of the effectiveness of R&D activities. A key observation is that patenting in information technology is among

[67]Ibid.

Table 5.—Federal and Department of Defense Obligations for Basic Research, Applied Research, and Development, 1983 (Estimated) (millions of dollars)

	Total R&D		Basic research		Applied research		Development	
Total Federal Government	$42,973.8	100 "/0	$5,765.2	100.0 "/0	$7,499.7	100.0%	$29,708.9	1OO.OO/o
Department of Defense	$24,519.6	57.1 %	$782.1	13.60/o	$2,543.9	33.9 "/0	$21,193.6	71.30/0

SOURCE: National Science Foundation, "Federal Funds for Research and Development Fiscal Years 1981, 1962, and 1983," vol. XXXI, Detailed Statistical Tables (NSF 82-326) (Washington, DC: U.S. Government Printing Office, 1982), pp. 174, 179, 181, 183, Percentages calculated from data in the table. As cited in Boesman, "U.S. Civilian and Defense R&D Funding; Some Trends and Comparisons With Selected Industrialized Nations," Congressional Research Service, Library of Congress, Aug. 26, 1983.

Table 6.—Federal and Department of Defense Obligations for Basic and Applied Research by Field, 1983 (Estimated) (millions of dollars)

	Total Federal funds	DOD funds	DOD as a percentage of total Federal funds
Basic research:			
Electrical engineering	$103.8	$71.8	69.1 %
Computer sciences	73.0	40.0	54.8
Mathematics	100.7	42.6	42.3
Applied research:			
Electrical engineering	$520.5	$471.2	90.5 %
Computer sciences	91.5	79.4	86.7
Mathematics	48.5	13.9	28.6

SOURCE: National Science Foundation, "Federal Funds for Research and Development, Fiscal Years 1981, 1982, and 1983," vol. XXXI Detailed Statistical Tables (NSF 82-326) (Washington, DC: U.S. Government Printing Office, 1982), pp. 73, 75, 79, 82, 98, 101, 104, 109. Percentages calculated from data in the table. As cited in Boesman.

the most intensive of all technologies. U.S. patenting of foreign origin[68] in all technologies has doubled in the past two decades to 41 percent—indicating escalating world competition for U.S. patents in general. A small number of foreign multinational corporations have a dominant (but perhaps somewhat diminishing) role in the proportion of foreign-origin U.S. patents. These "multinationals" emphasize information technology patents. The overall picture derived from this review of patent data confirms the finding reported in chapter 3 that foreign competition in information technology is increasing.

U.S. Patent Data

The top 50 electrical patent categories (ranked by actual numeric growth in the number of patents) received 8,139 patents during 1978-80 time period (table 7). Within these categories, semiconductors and circuits accounted for 48 percent and computers 15 percent, respectively. In the computer category, General Purpose Programmable Digital Computer Systems was the most active, as in previous years, receiving 632 patent documents. Miscellaneous Digital Data Processing Systems received the second largest number of

Table 7.—Technology Distribution of the Top 50 U.S. Patent Electrical Categories 1978.80

Ranked by actual file growth	Percent of categories
Semiconductors and circuits	48%
Computers	15 %
Other	37 %
Total number of patents in the 50 patent categories	8,139

SOURCE: Tenth Report, Technology Assessment and Forecast, U.S. Patent and Trademark Office, U.S. Department of Commerce, November 1981, pp. 16, 24

patents in the electrical category, with 548 patent documents.[59]

Solid-state devices, integrated circuits, and transistor categories together account for 24 of the 50 categories in the total ranked by *actual* growth from 1978 to 1980.[60] The percent growth in the number of these patents generally ranges from about 40 percent to 59 percent.[61] Solid-state devices account for 8 of the 11 highest growth entries. Lasers, laminagraphy, and fiber optics are also among the information technology segments included in the high patent growth entries. The two subclasses of fiber optics inventions show patent

[58]The country origin of a patent is determined by the country of residence of the first named inventor.

[59]Tenth Report, Technology Assessment and Forecast, Patent and Trademark Office, U.S. Department of Commerce, November 1981, pp. 14-18.

'Actual growth is the numeric increase resulting from additions to the patent copies (including cross-reference copies) to the file in the 3-year period 1978-80, Ibid p. 11.

"Percent growth, as used by the U.S. Patent and Trademark Office, is computed by dividing the actual growth for the 3-year period examined (1978-80) by actual growth for the 8-year period (1975-80), and multiplying by 100. Ibid., p. 11.

growth rates of over 70 percent. The listing, in fact, is composed almost exclusively of information technology inventions. Computer technology patents showed growth rates of over 70 percent for the 1978-80 period, well above the average of 46 percent for all technologies during the same time period.[62]

There are reasons for caution against generalizations concerning the use of patent statistics—e.g., variations in the importance and the degree of "invention" of different patents; the propensity (or absence of it) of some companies, and perhaps countries, to patent as opposed to using other alternatives-e. g., trade secrets, or lead times in the market place; the cost factor as a disincentive to patenting, as well as concern for antitrust allegations based on patent dominance; rapid technological change (making patents of limited value); differences in the scope of patent categories that may give a misleading impression of substantial amount of patenting activity in a broadly scoped subcategory or vice versa.

Nevertheless, the evidence shown above clearly seems to support the observation that the level of patenting for information technology in the United States is vigorous and may be indicative of extensive R&D in this field.

Foreign-Origin U.S. Patents

In 1973 the U.S. Patent and Trademark Office (USPTO), began detailed documentation of foreign-origin patent activity through its Office of Technology Assessment and Forecast (OTAF). One of OTAF's reports,[63] which is cited extensively in this section, provides useful background and many important findings on foreign patenting in the United States. Among the findings are:

1. Because patents obtained in the United States convey no protection in other countries and vice versa, inventors tend to patent in more than one country, and especially in countries that represent large potential markets. As a consequence, U.S. patent statistics tend to mirror trends in technological activity worldwide.
2. Although foreign-origin patenting in all technologies averaged only 20 percent of the total U.S. patenting for the years 1963-66, the percentage share has continued to increase, reaching 40 percent of the total for the year 1980, and 41 percent for the 1981 to mid-1983 period.

Figure 5 illustrates the long-term decline in the number of U.S.-origin information technology patents granted in the United States between 1968 and 1981, and the relative leadership position of Japan compared to France, West Germany, and the United Kingdom. It is not clear as to why the total number of U.S. patents has declined steeply between 1971 and 1980, but the U.S. Patent and Trademark Office advises that except for Japan, the trend was worldwide during that period. (Note that in 1979 a shortage of funds at the Patent Office limited the number of U.S. patents granted, artificially lowering the total for that year).

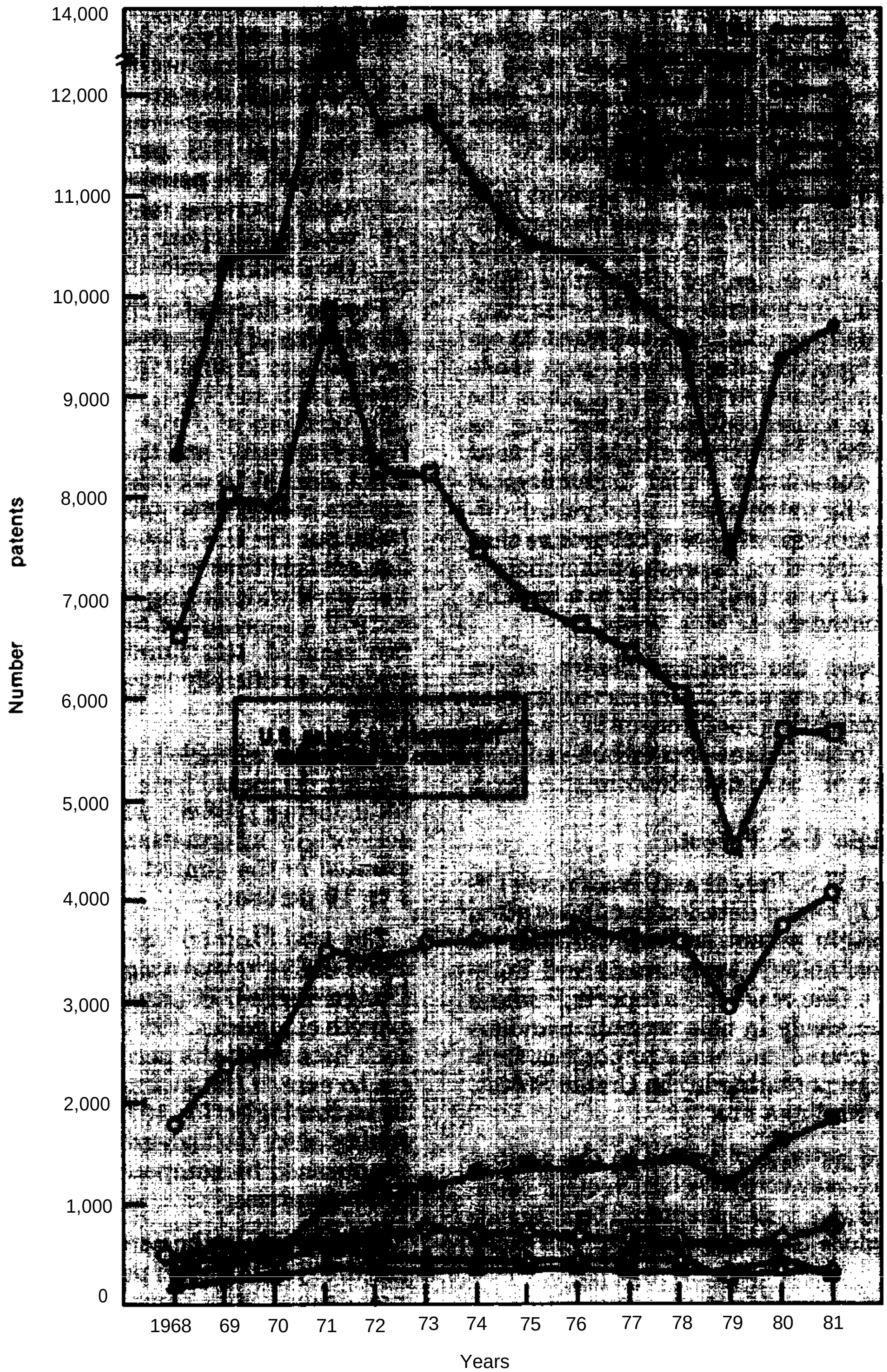
As shown by table 8, the share of U.S.-origin patents decreased from 79 to 58 percent of the total during 1968-81, while the share of Japanese-origin information technology patents granted in the United States increased from 3 to 19 percent.

The two "top 50" electrical category lists noted earlier reveal a significant proportion of foreign-origin U.S. patents in the high patent-growth categories. Fifty-four of the entries in both lists show the percentage of foreign origin to exceed the average of 38.5 percent for all technologies for 1978-80. This is not surprising, since the high-growth patent subclasses are pursued by companies in all of the developed countries.

Table 9 shows the percentage of foreign-origin U.S. patenting in patent category groupings dealing with some components of information technology. Three of the five category groupings examined (two in fiber optics and one in television) show foreign-origin patenting

[62] 1 bid., p. 22-26.
[63] Ibid., see for example, Section I, Part IV— "Most Foreign Active Patent Technologies, " pp. 27-32, and Section II, Patent Trends: Foreign Multinational Corporations Patenting Trends in the United States, pp. 33-46.

Figure 5.–U.S. Patents in Information Technology, SIC Codes 357, 365, 366, 367



SOURCE: U.S. Patent and Trademark Office, Office of Technology Assessment and Forecast.

Table 8.—Percentages of U.S. Patents Granted in Information Technology (IT) and in All Technologies (ALL), 1981

	United States		Japan		West Germany		United Kingdom		France	
Year	IT	ALL	IT	ALL	IT	ALL	IT	ALL	IT	ALL
1968	79	77	3	2	5	6	4	4	3	2
1981	58	60	19	13	8	10	4	4	4	3
1982	NA	59	NA	14	NA	9	NA	4	NA	3

NA—Not available
[a]Information Technology (IT) here includes SIC Codes 357, Office Computing and Accounting Machines; and 365-367, Communication Equipment and Electronic Components.

SOURCES The Office of Technology Assessment and Forecast, U.S Patent and Trademark Office, All Technologies Report, 1963-June 1983, and Indicators of the Patent Output of US. Industries (1963-81). IT numbers were calculated from data developed with assistance from the National Science Foundation, Science Indicators Unit.

Table 9.— Foreign-Origin U.S. Patents in Some Components of Information Technology

Title	Percent foreign origin 1/81-6/83
Light transmitting fiber, waveguide, or rod . . .	48.2°/0
Laser light sources and detectors	50.6°/0
Color and pseudo color television	52.8°/0
Active solid-state devices, e.g., transistors, solid-state diodes	40.80/o
General-purpose programmable digital computer systems and miscellaneous digital data processing systems	34.9°/0

NOTE The percent foreign origin is determined by dividing the total number of U S patents granted between January 1981 and June 1983 to foreign. resident Inventors by the total patents granted in the same time period, and multiplying by 100

SOURCE Off Ice of Technology Assessment and Forecast, Patent and Trademark Off Ice, U S Department of Commerce

to be significantly higher than the average of 41 percent.

Table 10 shows that in selected telecommunications categories, the Japanese share of foreign-owned U.S. patents ranges from 38 to 56 percent. For all categories of telecommunications, Japanese residents received 45 percent of the foreign origin U.S. patents from 1980-83.[64] Figure 6 depicts the shares of U.S. patents for communications equipment and electronic components among Japan, West Germany, and the United Kingdom.

These findings are consistent with comments from OTA workshop participants concerning the growing intensity of foreign competition in R&D. The statistics no doubt understate the level of foreign ownership of U.S. patents, since they do not take into account patents of U.S. origin that are controlled by foreign interests, e.g., patents issued to U.S. residents or companies that are foreign-owned or foreign-controlled, or the inclination of foreign multinational corporations to patent in other countries (see section below on Foreign Multinational Companies). Even understated, however, the intensity of foreign influence over U.S.-patented technology" is clearly significant. By way of providing perspective, it

[64]*Patent Profiles: Telecommunications*, **Patent and Trademark Office, Office of Technology Assessment and Forecast, U.S. Department of Commerce, August 1984, p. 15.**
[65]Ibid., **p. 4.**

Table 10.—Foreign-Owned U.S. Patents in Selected Telecommunications Classes, 1982

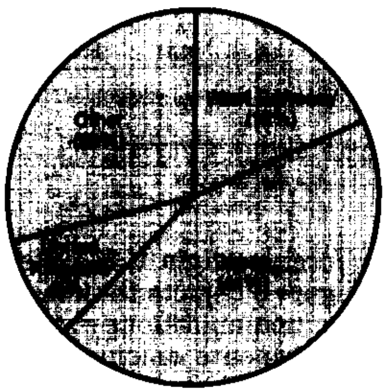
	Percent foreign of total	Percent Japanese of total	Percent Japanese of foreign
Telephony.	43%	17 "/0	390/0
Light wave communication	53 "/0	20 "/0	380/o
Analog carrier wave communications	43 "/0	240/o	560/o
Digital and pulse communications	40 "/0	160/0	38%

Telephony–Class 179/1R-1AA: 1AT-1FS, 1 H-1 MF, 1 MN-1SS, 1SW.106, 108 R-I9O
Light wave communications–372/43-59 & 75, 357/17 & 19, 455/600-619, 370/1.4, 350/96.1-96 34
Analog carrier wave communications—455/1-355
Digital and pulse communication (excludes light wave, Includes error detection and A/D & D/A conversion) —375/all subclasses; 371/1-6 & 30-71, 178/all subclasses, 340/347, AD-347, AD-347SY: 332/9 R-15, 329/104.109

SOURCE Reports prepared by Off Ice of Technology Assessment and Forecast for publication in late 1964

Figure 6.–Share of Foreign Patenting in the United States for the Three Most Active Countries in Selected Product Fields: 1981

Communication equipment
and electronic components



SOURCE: National Science Board, National Science Foundation, *Science indicators—19S2,* 1983.

should be noted that some other countries have an even higher percentage of foreign-origin patents, e.g., Canada, 93.4 percent; the United Kingdom, 84.2 percent; France, 67.6 percent. Japan has 16.6 Percent.[66]

[66] Industrial Patent Statistics, WIPO, 1982.

Foreign Multinational Corporations

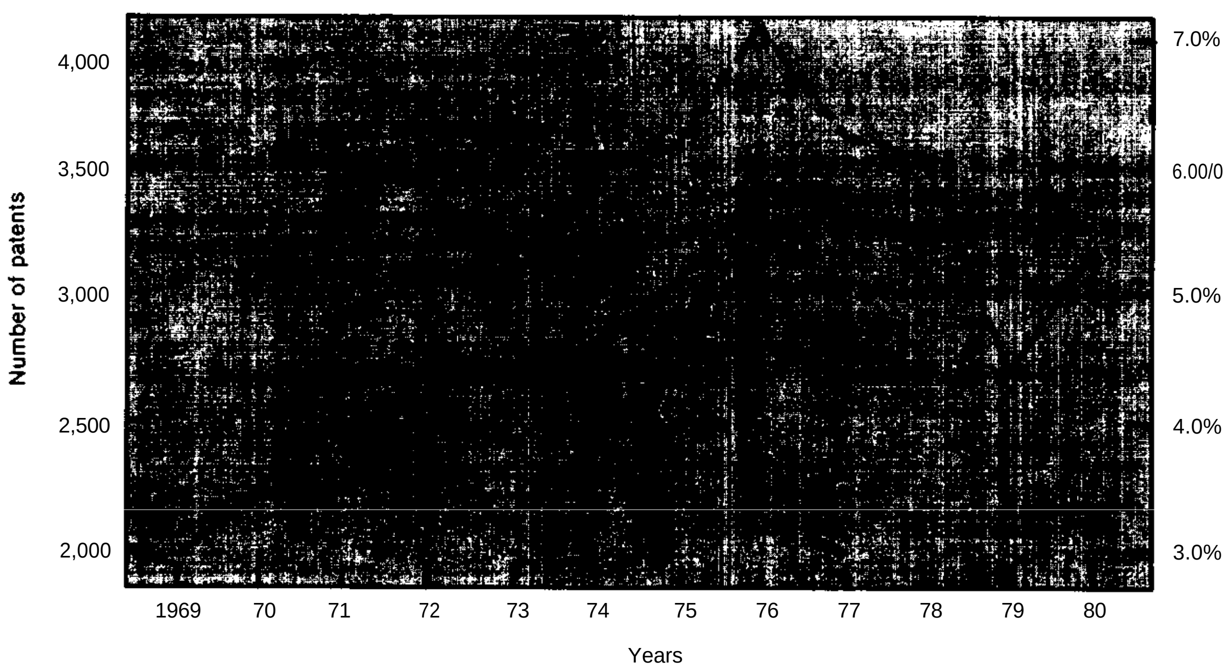
Another important OTAF finding concerns the role of foreign multinational corporations (FMNCs) in patenting. Taking into account the relative annual sales of the 10 major FMNCs and their ranking among the "Fortune 500" companies, OTAF has found a strong correlation between ranking by patents and sales level.[67] A comparison of the 10 FMNC's patenting with total U.S. patenting for 1969-80 is shown in figure 7.

In addition to noting that the FMNC's ownership of U.S. patents has recently (1980) leveled off to about 5.5 percent, the OTAF study observes that:

- The 10 FMNCs own or control, on the average, 4.7 percent of all U.S. patents granted each year.
- The extent of the 10 FMNC's ownership of U.S. patents doubled from 1969 to 1976–although the rate of increase had diminished to near zero by 1980.

[67] *Patent Profiles,* op. cit., p. 38.

Figure 7.—U.S. Patent Activity of 10 Foreign Multinational Corporations, 1969-80



SOURCE: Tenth Report, Technology Assessment and Forecast, Patent and Trademark Office, U.S. Department of Commerce, November 1981, p. 38.

- More recently, (1979-80) the percentage of U.S. patents granted to the 10 FMNCs has begun to decline in proportion to total foreign origin U.S. patents suggesting a diminished role in ownership of U.S. patents for these particular FMNCs.

The trend, while changing, shows that about one in every eight U.S. patents of foreign origin is owned or controlled by only 10 FMNCs[68]—an indication of the concentration of foreign-owned U.S. patents by a few multinational firms.

[68] Ibid. (OTAF Study), p. 40.

These statistics further confirm the testimony of OTA workshop participants concerning growing foreign competition in information technology R&D, and the observation that other countries have developed national policies and programs that target information technology.

A Synthesis: The Changing U.S. R&D Environment

Some measures, such as investment in R&D and growth in profits, indicate that R&D in U.S. information technology is vigorous. Other measures, such as competition in advanced-technology products and foreign ownership of U.S. patents, indicate a less robust situation. Thus, although information technology research and development is making marked advances, it is—at the same time-undergoing pressure from foreign competition. In response to the pressure, the participants in the R&D process are initiating a variety of changes. These changes are discussed in later chapters of this report.

Industry continues to invest heavily in information technology R&D–an indication of its belief in R&D's importance to competitive ness. The increasing costs of R&D are making new institutional arrangements such as joint research ventures and closer ties with universities more attractive. However, industry experts recognize that although R&D is necessary to competitiveness it is not sufficient to ensure it; other components of the innovation process are also important to maintaining competitiveness in international trade.

Universities are encouraging new institutional arrangements with industry, and the importance of their role in the R&D process (particularly in performing basic research) maybe growing. There are widespread problems relating to both the quantity and quality of university equipment and facilities for conducting information technology R&D, although these conditions may be improving. Some *State Governments* have become active in helping their universities to improve research capabilities and in encouraging university-industry pairings (see ch. 6).

Finally, the *Federal Government* has adopted policies intended to encourage private sector investment in R&D and to facilitate the transfer of technology from Government to industry. The Federal Government's (especially DOD's) expenditures for information technology R&D are growing rapidly and continue to have a strong influence on the direction of technological development in some information technology areas.

Observations

Some useful observations can be made based on the changes taking place in the U.S. R&D environment. First, the growth in foreign competition-whatever its effect on U.S. jobs and trade balances for the long term—is stimulating R&D investment, as shown in chapter 9. There has probably not been a time since the turn of the century when new products and product improvements have been marketed in such rapid succession as has been the case with information technology, nor a peacetime era when R&D had such a central role in the affairs of nations.

Second, the U.S. information technology industry *is* facing a "new world" of foreign competition. The intensive level of targeted and well-funded foreign competition is not likely to decline in the foreseeable future. Each of our major competitors' governments believe in the central importance of information technology as an essential ingredient for achieving economic, social, or national security goals, as well as the penalties-in terms of worsening trade balances and job losses—associated with falling by the wayside in the competitive race. As a consequence, they have established national policies and programs to enhance their domestic industrial position.

Third as foreign competition has inexorably strengthened in the post-World War II era, the broad margin of error that the United States once enjoyed has essentially vanished.

The long-term effects of several factors—national industrial policies, nontariff trade barriers (e.g., prohibiting the import of certain products or services, incentives for industrial innovation, interest rates, export controls—will determine the winners and losers, as nations maneuver to remain competitive. The United States will need to find ways to monitor its position relative to international competitors and to refine its policies as needed to keep in step with the changing global R&D environment.