Chapter 8

Information Technology R&D in the Context of U.S. Science and Technology Policy

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Chapter 8
Information Technology R&D in the Context of U.S. Science and Technology Policy

Findings

- Information technology is one of the most dynamic and controversial areas of U.S. science and technology due to its rapid pace of change, the emphasis placed on this technology for economic growth and for national security, and the pervasive or "core" nature of the technology and its effects.
- In this area there is a growing conflict between policies that emphasize basic research and policies that focus on international competitiveness and applications. These issues are prominent in information technology R&D because the lines between basic and applied research are so uncertain.
- Interest in coordinating Federal policy for information technology is intensifying, in part because of foreign government policies, growing costs for R&D, and growing concern for international competitiveness. Although coordination of various aspects of Federal policy has been debated for decades, it is a particularly salient issue in information technology: many Government agencies are involved, but none devote high-level policy attention to this area. The advantages of centralization or coordination are that it could save money and more effectively focus R&D in critical areas; the possible disadvantages include the establishment of a cumbersome bureaucracy and the loss of agency autonomy and flexibility.
- The dominance of the Department of Defense in information technology R&D has raised questions: Is military work siphoning off too much talent from civilian applications? Is the military work changing the direction of research in information technology in ways that are disadvantageous for the commercial sector or for the public? And are existing efforts to transfer technology from military to commercial applications adequate? Evidence currently suggests that there are growing problems in this area.
- Current policies and practices toward information technology R&D conflict with the realities of increasing international competition. The situation may call for a more sophisticated Government role in monitoring and support of industry and research.

Introduction

Earlier chapters documented the rapid changes occurring in information technology research and development. The technologies themselves continue to change in cost, power, and the variety of functions they can perform. At the same time, institutional structures for

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R&D are quickly evolving, international competition is intensifying, and the technology's impact on a wide range of social issues and problems is increasingly prominent. Because information technology is pervasive, its effects cascade through many aspects of society—from science itself to education, business, and defense–and at each point create seemingly independent changes and conflicts.

These changes are bringing increased attention to U.S. policy toward information technology R&D. In particular, Japanese and European policies, as noted in chapter 7, have brought increasing demands for U.S. policy re sponses.

Because the effects of information technology are so wide-ranging, any policy to respond to this technology must consider not only actions within specific issue areas such as manpower, but also broader issues in science and technology policy, such as the organization of Government and the roles of different agencies in R&D. The purpose of this chapter is to examine these more general frameworks for policy toward information technology R&D.

The chapter is divided into two major sections. The first begins with some brief background on science and technology policy in the United States, and the forces that have affected this policy as it has unfolded over the last few decades. Then, the chapter shows how these broad policies and forces set the context for and are closely tied to policy toward information technology. In the second section of the chapter, OTA discusses three key areas that are central to the science and technology policy issues raised by information technology R&D. The areas are the organization of Government, the balance of military and civilian roles, and policy measures to enhance international competitiveness.

Part I: Background

General U.S. Science and Technology Policies

Historically, science policy has been the term used to describe the actions of Government that affect the funding, organization, performance, and use of science.[1] The term has included policy for technology and engineering as well as for science. More recently, however, as technology has played a more prominent role in society and industry, many experts view "science policy" as inadequate in addressing concerns of technology.[2] The term "technology policy" has been used increasingly to refer to policy measures much more directly related to development and use of technologies, particularly as they relate to international competitiveness. In some recent discussions of industrial policy, technology policy has sometimes been considered an element of, or even a synonym for, industrial policy.

Table 45 sketches some of the actors and policy tools involved in both science and technology policy. The two types of policies have different, yet overlapping, constituencies and goals. In an area such as information technology, where "science" and "technology" are often commingled, the boundary between science policy and technology policy is vague. Recent statements of science policy (box A) illustrate the priorities of various policymakers, and show how science and technology are often mentioned together and blurred in the formation of policy. Note that although executive branch statements of science policy may be the most visible, other actors in the science policymaking arena-particularly Congress

[1] Science Policy Research Division, Congressional Research Service, *Science Policy, A Working Glossary* (Washington, DC: U.S. Government Printing Office, 1976).

[2] See, for example, J. J.Baruch, "The Cultures of Science and Technology," *Science,* Apr. 6, 1984. Baruch argues that lumping science and technology policy together is unwise, since the two enterprises have quite different approaches, goals, and needs.

Table 45.—Policy Tools, Actors, and Goals of Science Policy and Technology Policy

Science Policy[a]	Technology Policy[a]
Primary policy tools:	***Primary policy tools***
Funding of basic research	Mission-oriented R&D funding
Scientific manpower and education measures	Engineering manpower and education measures
Science information dissemination	Technology transfer mechanisms
International exchange programs	Limits on international flow of technology and information
	R&D tax credits
	Standards and patent policies
	University/industry research collaboration
Primary Actors:	***Primary Actors:***
Office of Science and Technology Policy (The White House)	Office of Science and Technology Policy
National Science Foundation, National Science Board	National Science Foundation
National Academy of Sciences	National Academy of Engineering
Agencies conducting basic research, e.g., Department of Defense, National Institutes of Health	Mission agencies—e.g., Departments of Defense, Energy, the National Aeronautics and Space Administration
Congress	Congress
University science community	Industrial R&D community
American Association for the Advancement of Science	Industry associations—e.g., Information Industry Association
Professional societies—e.g., American Medical Association, American Chemical Society	Professional societies—e.g., Institute for Electrical and Electronics Engineers, Association for Computing Machinery
	Department of Commerce—International Trade Administration, National Bureau of Standards, National Telecommunications and Information Administration
Social goals:	***Social goals:***
Quality of life	Economic well-being
Knowledge for knowledge's sake	National security
Equity, education	Technological leadership

[a]"Science policy" and "technology policy" are often difficult to separate. The policy tools, actors, and goals listed under each category are those that tend to be associated with science policy or with technology policy However, in many practical situations, the issues and actors are intertwined.

SOURCE" Office of Technology Assessment

and the scientists and engineers themselves—have a strong (some would say dominant) influence over actual policy.

A brief history of U.S. science policy (which, as noted above, has usually been defined to include technology policy) is helpful in order to provide a context for the gradual unfolding of policy toward information technology.[3] U.S. science policy has evolved since the 1940s out of tension between two fundamental premises:

1. that research should be supported in order to push ahead the frontiers of human understanding ("science for the sake of science"), lay the groundwork for technological advances, and train future scientists and engineers; and

[3]This chapter's analysis of science and technology policy is a synthesis of published books, articles, statements and legislation; in addition, OTA and its contractor (J. F. Coates, Inc.) conducted interviews with several dozen science policy experts. OTA is indebted to this group (see acknowledgments at the front of this volume) for their insights and assistance, although OTA takes full responsibility for the content of this report. For a fuller elaboration of history and issues in science policy, readers should consult, for example: Harvey Brooks, *The Government of Science* (Cambridge, MA: MIT Press, 1968); W. Henry Larnbright, *Governing Science and Technology* (New York: Oxford University Press, 1976); Daniel S. Greenberg, *The Politics of Pure Science* (New York: New American Library, 1971); A. Hunter Dupree, *Science in the Federal Government* (Cambridge, MA: Harvard University Press, 1953); U.S. General Accounting Office, *Major Science and Technology Issues* (Washington, DC: GAO, Jan. 30, 1981); Congressional Budget Office, *Federal Support for R&D and Innovation* (Washington, DC: CBO, April 1984); Science Policy Research Division, Congressional Research Service, National *Science Board: Science Policy and Management for the National Science Foundation, 1988-1980,* January 1983; Frank Press, "Science and Technology in the White House, 1977 to 1980, " *Science,* Jan. 9, 1981, pp. 139-145, and Jan, 16, 1981, pp. 249-256; and the annual series of reports on R&D from the American Association for the Advancement of Science. For a comprehensive view of the role of one key player in science policymaking, see *Toward the Endless Frontier: History of the Committee on Science and Technology, 1959-79,* House Science and Technology Committee Print (Washington, DC: U.S. Government Printing Office, 1980).

Box A.—Science Policy Statements

From *Chemical and Engineering News*, January 1982 interview with Science Advisor George Keyworth:

C&EN: What would be the distinguishing feature of this Administration's science policy as you would shape it?

Keyworth: Three things. Concentration on basic research. Second, trying to decrease the federal role in the support in the near term of technology that the private sector can support, like synthetic fuels. And third, and most important, is the requirement to discriminate upon the areas where the return on the federal investment merits the costs in a time of fiscal duress.

What I'm trying to do is define the word, discrimination. In basic research it is relatively simple. What we are trying to do is support those areas where the promise is greatest, where likelihood of major advances in our understanding of nature is greatest, and in other areas, more applied science and technology where federal responsibility is clear and where there is real need.

One example would be microelectronics. The semiconductor industry in this country is a major high-technology industry facing increased competition from other nations. I think it is important that the federal role, in addition to what can be accomplished by tax incentives, maintain support for basic condensed matter science that influences future breakthroughs in our understanding of semiconductor technology. In other words, selecting the areas where you are going to invest your federal R&D dollars as well as investing in the people and the institutions that have the most promise for achieving excellence.

From Public Law 94-282, National Science and Technology Policy, Organization and Priorities Act of 1976:

SEC. 102 (a) Principles.—In view of the foregoing, the Congress declares that the United States shall adhere to a national policy for science and technology which includes the following principles:

(1) The continuing development and implementation of strategies for determining and achieving the appropriate scope, level, direction, and extent of scientific and technological efforts based upon a continuous appraisal of the role of science and technology in achieving goals and formulating policies of the United States, and reflecting the views of State and local governments and representative public groups.

(2) The enlistment of science and technology to foster a healthy economy in which the directions of growth and innovation are compatible with the prudent and frugal use of resources and with the preservation of a benign environment.

(3) The enlistment of science and technology operations so as to serve domestic needs while promoting foreign policy objectives.

(4) the recruitment, education, training, retraining, and beneficial use of adequate numbers of scientists, engineers, and technologists, and the promotion by the Federal Government of the effective and efficient utilization in the national interest of the Nation's human resources in science, engineering, and technology.

(5) The development and maintenance of a solid base for science and technology in the United States, including: (A) strong participation of and cooperative relationships with State and local governments and the private sector; (B) the maintenance and strengthening of diversified scientific and technological capabilities in government, industry, and the universities, and the encouragement of independent initiatives based on such capabilities, together with elimination of needless barriers to scientific and technological innovation; (C) effective management of dissemination of scientific and technological information; (D) establishment of essential scientific, technical and industrial standards and measurement and test methods; and (E) promotion of increased public understanding of science and technology.

(6) The recognition that, as changing circumstances require periodic revision and adaptation of title I of this Act, the Federal Government is responsible for identifying and interpreting the changes in those circumstances as they occur, and for effecting subsequent changes in title I as appropriate.

From President Carter's 1979 message to Congress on Science and Technology:

Yet despite the centrality of science and technology in our lives, the Federal government has rarely articulated a science and technology policy, This message sets forth that policy. The thesis is that new technologies can aid in the solution of many of our Nation's problems, These technologies in turn depend upon a fund of knowledge derived from bade research. The Federal government should therefore increase its support both for basic research and, where appropriate, for the application of new technologies. . .

The Federal government's support of research and development is criticaI to the overall advance of science and technology. Federal responsibility lies in three major categories:

1. The largest fraction of Federal investment serves the government's direct needs such as defense, space, and air traffic control. . .
2. The Federal government undertakes research and development where there is a national need to accelerate the rate of development of new technologies in the private sector. . . . when the risk is great or the costs are inordinately high. , . .
3. The Federal government supports basic research to meet broad economic and social needs. . . .

The majority of Federal support for basic research is in the mission agencies.

From the White House Office of Science and Technology PoIicy's 1982 Annual Science and Technology Report to the Congress:

The U.S. science policy is

- to enhance the contribution of science to the two most pressing long-term needs of the United States: national defense and the international competitiveness of U.S. industry.
- To maximize the return on national R&D investments; and
- To ensure the long-term vitality of the U.S. science and technology base.

The strategy to implement U.S. science poLicy

- Emphasizes excellence–in research results and in people:
- Stresses the importance of scientific relevance to national needs, and more clearly defines the appropriate roles of the Government and the private sector in supporting R&D;
- Facilitates cooperation in scientific research among Government, industry, and academia;
- Seeks to support sufficient basic and long-term applied research to ensure that the United States maintains the world's strongest science and technology enterprise;
- Emphasizes the importance of having the leading research universities in the world and of training the highest quality scientists and engineers to ensure continued U.S. qualitative leaderShip; and . . . .
- Allocates Federal R&D resources to support this strategy..

The U.S. technology policy is to ensure that U.S. ***scientific leadership*** results in economic and defense leadership.

The strategy to implement U.S. technology policy'

- Provides tax and other incentives to the private sector for commercial R&D;
- Continues to emphasize the different private sector and government roles in developing new technologies, products, and processes so as not to discourage private sector initiative with the threat of Government intervention and competition;
- Improves the climate of cooperation so that maximum cross-stimuli occur among Government, industry, and academia;
- Improves the ability of Federal laboratories to contribute to U.S, industry, and also takes advantage of foreign research results;
- Encourages the change in industry's outlook to emphasize long-term viability rather than only short-term gain;
- Recognizes that the service sector in the U.S. economy is gaining in importance, and focuses emphasis on R&D accordingly; and
- Recognizes the effect of economic and regulatory policies on U.S. science and technology and, ultimately, on U.S. economic competitiveness.

2. that the investment of public resources in research should be moderated and directed at specified high-priority national needs, to which the private sector is unwilling or unable to respond.

The first principle was embodied in the creation of the National Science Foundation and the National Institutes of Health to manage the distribution of public funds to support basic research. The primary mechanism for this support is research grants, which are made in response to requests by recognized scientists and validated by the judgment of their peers.

The roots of the second principle, which underlies all "mission-oriented" Government-funded research, go far back into our national history. The second principle is evident in the science policy statements of box A, particularly those from the Reagan administration, which emphasize the payoffs of science and technology for the economy and defense.

The accountability and focus indicated by the second premise is often at odds with basic research, which sets its own directions and often leads investigators down blind alleys or toward ends that may have no immediate or foreseeable practical applications.

Until the 1940s, most federally supported research was closely related to well-established Government responsibilities such as defense or exploration and development in the West, or to areas basic to the national economy (agriculture, water, and public health). After World War II, leaders such as Vannevar Bush–realizing that we had entered an era of rapid advancement in scientific knowledge that could create new technologies and industries-forcefully led the Nation to accept increased, systematic, and continuing support for science through funding of basic research and science education.[4]

[4]See Vannevar Bush, "Science, the Endless Frontier: A Report to the President on a program for Postwar Scientific Research, " originally published in 1945, reprinted by the National Science Foundation, Washington, DC, 1960.

The clearest landmark event in the post-war era was the Soviet launch of Sputnik in 1957, which had two major kinds of effects. The response to Sputnik-the technological venture to put a man on the Moon, and bring him back, by the end of the decade of the 1960s–was unique for a non-war effort in having a singular clarity of mission and unequivocal criteria for success. This mission galvanized a large portion of the scientific and technological enterprise to a single clear goal. The second, more diffuse consequence was to redirect the Nation's attention, albeit for only a brief period, to science, science education and new scientific opportunities.

The premises of science policy, as described above, have gradually evolved into a set of relatively consistent basic tenets or assumptions that guide Government's actions. OTA derived the science policy statements in table 46 primarily from the practices and behavior of U.S. policymakers and institutions over the past 25 years, as well as from published statements and policies and interviews with science policy analysts. Although these principles have been relatively stable, they may contradict one another and come into conflict in special cases, and exceptions could certainly be found for each item in the list. Furthermore, they have rarely been stated explicitly; instead, they are embodied in a diverse collection of decisions, practices, and legislation. While table 46 is in no way a complete set of the principles which guide U.S. science policy, the essential tenets relevant to information technology are included.

Each of the science policy statements displayed in table 46 has varied in importance and salience in driving programs, projects, and organizational relationships. Often, the processes by which a policy issue is resolved result in an overcorrection of some situation which, in turn, later leads to the recognition that the pendulum has swung too far. For example, the advent of Sputnik was perceived to indicate that support for basic science had been too weak. On the other hand, the Mans-

Table 46.–Tenets of Science and Technology Policy, 1960-84

Basic Research

1. Basic research is a Federal mission.
2. The best model for conduct of the basic scientific enterprise is physical science, and in particular, physics.
3. Peer review will be the primary means for selecting topics for basic research. Management concerns will play a role in more mission oriented research.
4. Manpower for the scientific enterprise will be produced primarily as derivative of, and as an intimate part of, basic research at universities.
5. Social sciences will flourish under the traditional (physical science) model of scientific research. Social and interdisciplinary research are keys to the more effective application of knowledge to many classes of societal problems.

Mission Agency R&D

6. There is a useful and significant distinction between basic and applied research and between research, engineering, and technological applications. These distinctions are of primary value in defining the role of Government in relation to the general economy and the role of Government agencies in relation to their missions and to each other.
7. Mission agencies will define their knowledge needs which may be satisfied through R&D and present their case through the budget process.
8. Federal agencies are expected to undertake research in support of the commercial, business, and private sector insofar as support of that research will yield substantial public benefit, especially to the clients and constituents of that agency. Support is encouraged only in those cases where research to satisfy nongovernmental needs is unlikely to be adequately sustained by private initiative.

Defense R&D

9. Defense research, although a major part of U.S. R&D expenditures, will be treated as an isolated, separate case with the expectation that side benefits will accrue to the larger scientific and industrial community.
10. DOD will have a restricted and limited role in support of basic and social research at universities. This policy, manifested in the Mansfield amendment under the renewed pressures of the Cold War, has been relaxed.

Organization of Government

11. Voluntary coordination, rather than legislative or centralized control and coercion, will be the primary instrument by which programs in and among agencies will be integrated, Coordination will be a primary mechanism for assuring completeness of coverage of essential fields and the primary instrument for reducing overlap and redundant budgets and programs.
12. At the Executive level, the Office of Management and Budget will exercise its statutory role in assuring that mission needs are met and that research and development programs are reasonable and realistic. There is also a role for a White House science policy advice mechanism.
13. In the Congress, oversight, both general and budgetary, will be the primary technique by which quality, completeness, and fullness will be assured.
14. Planning for science and setting the agenda for science and technology are best handled by the mission agencies or the specific disciplines.
15. Public and stakeholder participation in science and technology decisionmaking is appropriate, desirable, and encouraged.

Special Federal Roles

16. The Federal Government will help assure the strength of the research system by collecting, analyzing, and disseminating information on subjects such as science, scientific and engineering manpower, and technological innovation.
17. National laboratories are general assets to the nation, well beyond the particular missions for which they were established.

R&D Funding

18. The scientific community may operate on the assumption that there is a firm long-term implicit commitment to incremental funding increases.
19. To avoid disturbances in the established pattern of support for science, the identification of new problems, issues, and options will be handled primarily by budget augmentation, rather than by reprogramming of existing programs. The primary instrument for effective infusion of money in large quantities for new scientific enterprises will be the establishment of an office, a bureau, an agency, or a division.
20. In most fields, the most appropriate method of support will be funding individual projects by individual investigators.
21. On large expensive basic science projects, the Federal role is to provide large block funding and long-term support. It will stand clear of the programmatic side of those activities.

Nonfederal R&D

22. Both basic and applied research in the commercial sector is best and most effectively handled by individual corporations and will best prosper under competition. To facilitate that development certain public strategies, such as patents, copyrights, tax write-offs, and a variety of other measures are appropriate for Government. American commercial research requires no particular Government intervention, attention, or assistance, since it can cope with any foreign competition.
23. Applied research "applicable to the private and nonfederal public sector requires little attention. It will take care of itself.
24. Good relationships between universities and industry are beneficial to both institutions, and Government will act to support such relationships, but not directly intervene.

Utilization of Research

25 The free and open dissemination of research results, except those of a commercial proprietary sort or affecting national security, is the best guarantee of the effective use of new knowledge in the service of the nation.

26 With regard to basic research, technology transfer, that is, the practical use of research results, is best handled by the delivery of scientific information through journals and monographs. Commercial use best occurs through scientific channels, through the employment of university scientists as consultants, and through private sec-

Table 46.—Tenents of Science and Technology Policy, 1960-84—continued

tor organizations assuming responsibility for remaining alert to developments in their own interests.

27. Mission agencies have the primary responsibility for getting the scientific and technical results of research to potential users within their mission areas.
28. It is in the national interest to deprive Iron Curtain countries of the benefits of Western, that is American, science and technology. Consequently, systematic restraints will be placed upon trade and exchange where appropriate, primarily at the discretion and behest of the national security establishment.

Technology

29. Policy toward technology is unnecessary or will be treated as an adjunct to science policy. This policy has, of course, come under some challenge in the last few years.

SOURCE: OTA analysis, interviews with science policy experts, and synthesis of published materials. See footnote 3. Note that these are statements of underlying policies, and there are exceptions and contradictions to each statement

field amendment[6] was a rebuke to DOD for obscuring the distinction between basic and mission-oriented research, but it also swung Government away from the Sputnik-induced changes and back toward accountability and strictly defined applied research.

Nevertheless, most of the principles highlighted in table 46 have remained effective and functional over the past quarter-century. As general science policies they influence research and development in the area of information technology. While many of these influences are subtle or indirect, the principles shown in table 46 can be seen in the current situation. For example, the U.S. Government's position toward the global market, reflecting the propositions above, is that industrial competition will deal effectively with issues of international competition and no special Government policy is required. This is in sharp contrast, of course, to Japanese and European strategies, as noted in chapter 7, and this contrast has intensified the debate about appropriate Federal roles in international competitiveness. While these are largely issues of trade policy, there are strong connections between trade and science policies, especially in information technology.

Other aspects of policy toward information technology R&D that stem directly from these general science policies include the separation of military and civilian research in information technology R&D, and the implicit belief that the market process will take care of the downstream social effects of information technology. The next section of this chapter will set forth policies toward information technology R&D in more detail.

Since 1960, several important trends and forces have affected both general science policy and policies toward information technology R&D in particular. Table 47 highlights some of these forces. As is evident from the second column of table 47, many of the forces affecting science policy generally have been particularly prominent in information technology R&D. In some respects, policy toward information technology R&D is the leading edge of issues in science and technology policy. This is in large part due to the rapid pace of change in information technology, the emphasis placed on information technology for economic growth and for national security, and the pervasive or "core" nature of the technology.

Information Technology R&D Policies

Like general science and technology policies, policies toward information technology R&D are not often explicit or coordinated. Instead there have been many decisions, actions, state ments, and organizations, which taken togeth-

[6] As described in W. C. Boesman, "U.S. Civilian and Defense Research and Development Funding," Congressional Research Service, Science Policy Research Division, Aug. 29, 1983, p. 23:

> Even after the establishment of the National Science Foundation, whose mission is the support of basic and applied research and education in the sciences, DOD continued to fund a significant amount of basic research until, in 1969, the Congress passed the "Mansfield amendment" to the fiscal year 1970 military procurement authorization which prohibited funds authorized by that law from being used to conduct R&D not having "a direct and apparent relationship to a specific military function or operation."
>
> The following year, the Congress passed the "modified Mansfield amendment" to the fiscal year 1971 military procurement authorization which prohibited funds authorized by that "or any other Act" from being used to conduct R&D unless the Secretary of Defense determines the existence "of a potential relationship to a military function or operation."

Table 47.— Forces Affecting Science and Technology Policy Since 1960

Trend or force	Implications for R&D in information technology
1. *Growing pervasiveness of science and technology in society.* This is accompanied by rapid blurring of traditional distinctions between basic and applied research, and between science and technology.	Information technology is one of the most vivid examples of this growing pervasiveness. The intertwined nature of basic and applied work, and of information science and technology, raises questions about appropriate Federal roles, which have traditionally been based on those distinctions.
2. */integration of the global economy.* This is accompanied by an increase in international competition, a challenge to U.S. supremacy in certain research areas, and a growing consensus that U.S. industries are not invincible and may need help.	Information technology is an area in which these challenges have become quite intense: while we still lead in most areas of R&D, our lead is narrowing, and our ability to use our technological leadership in applications for economic gain is in question. The margin of error for actions in information technology R&D has been dramatically reduced because of international competition.
3. *The shifting role of the Department of Defense.* DOD sponsorship of R&D was dominant in the post war era, then was shifted away from basic research and other agencies played stronger roles. Now DOD is once again dominant in most areas of R&D funding, although the funding is much more directed than it was after World War II.	DOD was an early and strong supporter of many areas of information technology. 70-80 percent of Federal funding for R&D in information technology now comes from DOD. In certain areas (e.g., artificial intelligence, software engineering), DOD continues to be a very strong influence on the directions for R&D.
4. *The side effects of technology.* The public seems to have grown increasingly wary of technology, particularly in the '60s and '70s. At the same time, science and technology are viewed as a way out of our economic malaise.	Though there are concerns about privacy and equity issues, use of information technology seems to be viewed as inevitable, and, in many cases, desirable. R&D in information technology, as the basis for innovations, is viewed as essential to support an economy heavily oriented toward high technology.
5. *Big budgets for R&D.* Demand for accountability has grown as R&D budgets have swelled and agencies have undertaken major projects (e.g., accelerators, weapons systems).	The demand for accountability has just begun in information technology R&D, particularly in major software projects, or use of supercomputers. Universities in particular are squeezed by rapidly rising costs for this research.
6. *Internal upheaval in the science enterprise.* The decade-long search for a more effective science policy apparatus has bounced around government, focusing at various times on agencies such as NSF and OSTP. None have been conspicuously effective in a broad-scale science policy role.	Information technology R&D is acutely affected by the multiplicity of agencies and roles in setting policy. Because of the technology's pervasiveness, more than a dozen agencies set policy for R&D in information technology. None of them have devoted high-level policy attention to information technology; it tends to be viewed as a tool.

SOURCE OTA analysls, !ntervlews with science and technology policy experts, and synthesis of published material. See footnote 3

er comprise the de facto U.S. information technology R&D policy. Using techniques similar to those used to develop table 46—i.e., analysis of published material and the actions of policymakers, and discussions with policy experts—OTA produced a list of policies specifically related to information technology R&D, which are displayed in table 48. Each of these, elaborated below, can be seen to stem relatively directly from one or more of the tenets outlined in table 46. Note that the following are statements of the effective principles that appear to underlie Government's actions over the past quarter-century. As in the statements of general science policies, OTA has made no judgment that they are necessarily appropriate at present or in the future.

1. The Federal Government has operated under the assumption that the United States should not be dependent on foreign information technologies to ensure its national security.

A primary mission area for information technology R&D is national security. Defense spending dominates Federal support in this area of R&D. The U.S. position as leader of the Western military alliance has led to a commitment to keep the United States at the forefront of information technology developments.

Table 48.-Federal Government Policies Toward information Technology R&D

1. The Federal Government has operated under the assumption that the United States should not be dependent on foreign technologies to ensure its national security.
2. Information technology R&D has been funded separately for civilian and military applications.
3. R&D priorities have been set in Government by mission agencies, and in commercial application areas by the private sector.
4. The Federal Government has assumed that it should promote continuous innovation in information technology.
5. The market has been assumed to be the best mechanism to bring the civilian benefits of R&D in information technology to society.
6. The market has been the primary means to attend to the consequences and effects of information technologies.
7. Where necessary, the Government has used traditional means for regulating the behavior of firms in information technology industries.
8. The short- and long-term manpower needs of information technology R&D have been addressed through traditional means.
9. Government has followed industry's lead in setting standards except where Government is a dominant purchaser.
10. The Federal Government has assumed that free trade policies benefit the United States in the long term.
11. U.S. Government has restricted the export of sensitive technical information, as well as advanced information technology itself, to Eastern Bloc nations.
12. The primary international role for the U.S. Government in information technology has been to promote equitable use of common global resources.

SOURCE: See text.

2. Information technology R&D has been funded separately for civilian and military applications.

This policy is not unique to information technology R&D. It assumes that a useful distinction can be drawn between civilian and military uses of information technology. It also assumes that there is little overlap between the civilian and military uses in this area, and that where such overlap exists, as in weather forecasting, the results of military R&D will find their way into commercial uses. In a few cases, there are small transfers of funds from military to civilian agencies performing R&D.

3. R&D priorities have been set in Government by mission agencies, and in commercial application areas by the private sector.

Government sees information technology as a tool. Therefore, information technology R&D is decentralized. Each agency sets its own R&D priorities—the National Weather Service, U.S. Postal Service, the Department of the Treasury, the Federal Aviation Administration, the Federal Reserve Board, and so on. This area of R&D has not received high level or coordinated policy attention.

4. The Federal Government has assumed that it should promote continuous growth and change in information technology.

Innovation in information technology is viewed as overwhelmingly beneficial to society. On the military side, Government seeks continual innovation in order to keep ahead or abreast of potential adversaries. On the civil side, the contributions of information technology to productivity argue for continued advances to keep the U.S. economy prosperous. On the other hand, the concentration on innovation tends to shift attention, especially within Federal R&D, to new and glamorous technologies and away from improving or reducing the costs of existing technologies.[6]

5. The market has been assumed to be the best mechanism to bring the civilian benefits of R&Din information technology to society.

For the most part Government policy has assumed that the market will identify and meet the needs of society for information technology and that the market will make the appropriate investments in R&D to meet those needs. Similarly, Government policy has assumed that industry will develop the supporting technologies and infrastructure such as software quality control processes as part of meeting the market's needs.

Government frequently encourages innovation in the private sector through indirect measures such as procurement and tax allowances. In cases where developments are important to the national interest, such as national electronic mail, Government has used R&D

[6] See L. Thurow, "The relationship between defense-related and civilian-oriented research and development priorities, " in *Priorities and Efficiency in Federal Research and Development*, a compendium of papers submitted to the Subcommittee on Priorities and Economy in Government of the Joint Economic Committee of the Congress, Oct. 29, 1976.

contracts to promote innovation while limiting the risks to industry.

6. The market has been the primary means to attend to the consequences and effects of information technologies.

This policy assumes positive impacts will result in new markets, while producers will reduce adverse impacts in order to remove impediments to present and future applications. Protection of individual rights is the major exception to the reliance on the market. The Congress, the executive branch, and the courts have all attempted to cope with the issues of individual privacy, intellectual property, and freedom of access. For the most part, the assumption underlying their deliberations and actions is that traditional legal, regulatory, or organizational mechanisms can handle these issues.

7. Where necessary, the Government has used traditional means for regulating the behavior of firms in information technology industries.

Historically, the Government seems to have assumed that there is nothing special about information technology industries. Government has not seen antitrust, patent, tax and other regulatory policies as major impediments to innovation. For the past half-century, Government has assumed that: 1) regulated monopolies such as AT&T are effective performers of R&D; and 2) developments in regulated and unregulated areas of telecommunications and computers are not in conflict.

8. The short- and long-term manpower needs of information technology R&D have been addressed through traditional means.

As noted in chapter 5, the Government has relied on the universities to meet the needs of the market for the trained scientists and engineers necessary for innovation in information technology. Support of research in information technology at universities is the primary method by which the Federal Government supports manpower development in the field. Government has also assumed that the universities, assisted by various subsidies, will make the necessary investments in equipment to provide the appropriate training for these future information scientists and engineers.

9. Government has followed industry's lead in setting standards except where Government is a dominant purchaser.

Government treats information technology like any other industrial product in terms of standards, relying mostly on voluntary industry standards. When Government does get involved in standards-setting, it is usually at the request of industry. In the computer field, the Institute for Computer Sciences and Technology (ICST) at the National Bureau of Standards is responsible for developing standards for the Federal Government, and it also participates in and coordinates a variety of industry standards efforts. In certain cases such as computer networking standards, ICST has taken a firm leadership role, both domestically and internationally.[7]

10. The Federal Government has assumed that free trade policies benefit the United States in the long term.

From transistor radios to microchips, the U.S. Government has maintained a position of free trade in the area of information technology. The assumptions underlying this policy have been: 1) free trade will open up foreign markets for U.S. products, 2) the U.S. lead in information technology is largely unassailable, 3) the marginal benefits of lower costs to the consumer outweigh the threat to U.S. industry, and 4) competition promotes innovation.

This openness has included access to R&D through the published literature, licensing, joint ventures, and other commercial routes.

11. The U.S. Government has restricted the export of sensitive technical information, as well as advanced information technology itself, to Eastern bloc nations.

The importance of information technologies to U.S. national security has led to Government actions to preserve the superiority of U.S. in-

[7]J. H. Young, "Effects of Standards on Information Technology R& D," paper prepared for OTA, Nov. 25, 1983.

formation technology. One way is to prevent its adversaries from getting access to, for example, certain research publications, advanced chip designs or cryptography software. This policy assumes that: 1) the Government can effectively control the international operations of U.S. researchers and firms, 2) these controls will not unduly harm the viability of the U.S. information technology industry, and 3) the advantage of such controls outweighs harm done to the U.S. R&D enterprise through restriction of information flow among researchers.

12. The primary international role for the U.S. Government in information technology has been to promote equitable use of common global resources.

U.S. actions regarding international use of information technologies have focused on issues such as spectrum allocation, the use of the geosynchronous orbit, the international use of communications satellites, and access to data from weather and other Earth applications satellites.

Part II: Key Issue Areas

The previous section provided background on the nature of policies related to information technology R&D, and on the connections between those policies and broader science and technology policies. A central conclusion is that information technology R&D has been influenced to a substantial degree by policies applicable across many areas of science and technology. However, factors such as the reliance on information technology for economic growth and national security, and the pervasive, core nature of the technology, are increasingly stressing policy toward information technology R&D, focusing attention upon it, and setting it apart from policy for other areas of science and technology.

This section attempts to build on that foundation by examining three particular areas of policy toward information technology R&D that may be ripe for change or improvement. OTA selected the three issue areas because they are key problems for the future development of information technology R&D. Throughout this report, scores of issues have been identified which, in themselves, merit attention. The three issues discussed in this chapter are overarching, in that they subsume many of the earlier issues. Addressing these three areas could help set the direction for many of the more detailed issues. The first, and most fundamental, topic is the organization of Government to deal with information technology R&D. The second issue area is the balance of civilian and military funding in this area of R&D. The final area is international competitiveness.

ISSUE A: Organization of Government

Demands for coherent Federal policy towards information technology R&D conflict with the traditional system of pluralist decisionmaking by various agencies and the private sector.

Introduction

The search for coherence and effectiveness in science policy of all kinds has been the object of many commissions, proposals, legislative initiatives, and reorganization plans. A hundred years ago the first plan for developing a Department of Science and Technology was introduced in the Congress.[8] Several times in the 1970s and again within the last year, the idea of such a central department has reemerged.[9] The fundamental issue coming out of all such proposals is whether science is better managed through a central organization

[8] For a discussion see A. H. Dupree, *Science in the Federal Government*, Harvard University Press, 1953, p. xi.

[9] See, for example, H.R. 481, The National Technology Foundation Act, introduced Jan. 6, 1983, by Rep. George Brown, et al.

or as an adjunct to the missions of the Federal Government as reflected by the mission agencies.

While the proposals for a central Department of Science and Technology have consistently failed, the Nation has reorganized its science and technology apparatus several times to meet new and emerging needs. The Department of Energy, the Environmental Protection Agency (EPA), and the National Oceanic and Atmospheric Administration (NOAA) all resulted from the coalescence or rearrangement of diverse scientific and technical functions.

Nevertheless, the traditional Government organization for science in general is decentralized, pluralistic, and only loosely coordinated. The strong centralizing force on science comes from the annual budget review by the Office of Management and Budget. Even there, concern for scientific issues is for the most part split up along agency lines; for example, NASA is in one area, NOAA in another, and Defense science in still another. This pluralistic system of Federal policymaking has the advantages of allowing mission agencies to tailor R&D to their own needs, which is a basic tenet of science policy as discussed earlier. However, several trends are putting stress upon the ability of the current decentralized system to cope with new and emerging problems:

- Increasing international competition, and the presence of coordinated technology policies among our trading partners, are highlighting our absence of coordination and causing many to call for reexamination and change; and
- The costs of R&D of all kinds have risen. At the same time, there is increased pressure on the Federal budget from entitlements, defense, and the deficit. Some argue that a more coordinated and coherent Federal science and technology apparatus could be more cost-effective and accountable.

There is a broad spectrum of possibilities for coordination of Federal activities in science and technology areas, ranging from complete decentralization and pluralism to a central agency which handles the bulk of R&D funding and science policymaking. Despite the appeal of coordination in principle, it has costs that include decreased flexibility of mission agencies, creation of cumbersome bureaucracies, and potential loss of multiple funding avenues—and hence multiple approaches—for researchers. One report notes:

> Coordination is like motherhood; everyone agrees it must be done but it lacks an operational definition.
>
> Coordination is not a homogeneous activity; but rather an umbrella which encompasses many different activities performed by different people, for similar effect.
>
> Coordination requires significant effort at all levels of management and, therefore, both horizontal and vertical structures need to be considered.
>
> A certain amount of coordination is good for the health of Government, but like exercise, too much will cripple or kill.[10]

Consequently, most science policy experts argue that some combination of centralized decisionmaking, ad hoc coordination, and mission autonomy is appropriate.[11]

Dimensions of the Issue

Current responsibilities for information technology are dispersed all over Government—from the Department of Defense to the General Services Administration, from the Department of Justice to the Federal Communications Commission. The ad hoc nature of policy in this area is even more evident than most other types of science policy because agencies tend to see information technology as a tool, not as something warranting significant policy attention in itself. In addition, there are simply more agencies involved because of the pervasive nature of information technology.

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[10] W. A. Hahn, D. S. Alberts, and J. Lovelace, "Interagency Coordination: Workshop Report," in *The Management of Federal Research and Development: An Analysis of Major Issues and Processes* (McLean, VA: The Mitre Corp., 1977), pp. 93-97.

[11] See, for example, Harvey Brooks, *The Government of Science* (Cambridge, MA: MIT Press, 1968).

More than a dozen agencies fund or affect relevant R&D.[12]

There is, however, some coordination in Federal policy. To the extent that DOD dominates R&D funding, it is the de facto lead agency and informal or formal coordination point. And agencies often coordinate their work on an ad hoc basis. For example, the Defense Advanced Research Projects Agency (DARPA) and NSF brief each other on computer science research programs.[13] And ICST at the National Bureau of Standards has a group of senior officials from major agencies who advise the Institute on its programs.

Several specific factors focus attention on the degree of coordination and coherence in policy toward information technology R&D.[14] Among them:

- In general, there is a lack of high-level policy commitment in this area, which has several kinds of effects. One is that the role of mission agencies in information technology is shifting, uncertain and as divergent as the roles of those agencies themselves. Coordination would be useful in such subjects as database collection, R&D research topics, and compatibility of technology and information.
- Many have argued that there are substantial shortages of manpower. However, as discussed in chapter 5, the evidence for such shortages is inconclusive, except in certain very specific areas. The lack of reliable assessments of manpower and the associated uncertainties hinder policymaking in all areas of the Government that work with information technology.
- The Federal Government has an extensive network of national laboratories, although the quality and relevance of some of these facilities has periodically been in question.[15] Researchers at various national laboratories constitute the largest concentration of expertise in use of supercomputers. The question of how best to use the national labs in this and other fields of information technology R&D cuts across a variety of agencies, in particular the Departments of Defense and Energy.
- Related to use of the national labs, chapter 3 pointed out that researchers are increasingly requiring advanced computers or "supercomputers" to perform a wide variety of research. The question of where to house such machines and how to provide access is of concern to a wide variety of agencies involved with information technology R&D. Committees of the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) at OSTP have attempted to address this issue.
- As discussed in chapters 2 and 3, the emerging shared wisdom in the industry is that software is a key problem in cost and effectiveness of computing systems. Many believe that American industry has failed to give adequate research attention to software problems, preferring for a variety of reasons to emphasize hardware. The reliability and maintainability of software will become an increasingly large issue, raising questions of quality control, standards, manpower, and education policy for many agencies in the Federal Government with large information systems.

[12] These include the Department of Defense (itself divided into the Defense Advanced Research Projects Agency, the Office of Naval Research, the Air Force Office of Scientific Research and various other units in the Pentagon and the three services), the National Science Foundation, the Department of Commerce (largely through the National Bureau of Standards, the National Oceanic and Atmospheric Administration, and the National Telecommunications and Information Administration), the National Institutes of Health, the Department of Energy, the National Aeronautics and Space Administration, the Federal Aviation Administration, the Patent and Trademark Office, and the Department of Justice (both in their jurisdiction over antitrust, and in R&D for law enforcement systems).

[13] Elias Schutzman, National Science Foundation, personal communication, Mar. 2, 1984.

[14] For further elaboration of some of these factors and discussion of institutional options, see "Institutional Options for Addressing Information Policy Issues: A preliminary Framework for Analyzing the Choices," a staff memorandum prepared by the Communication and Information Technologies Program of OTA, Nov. 29, 1983.

[15] See the *Report of the White House Science Council Federal Laboratory Review Panel,* May 1983, sponsored by the Office of Science and Technology Policy. (Also called "The Packard Report," after its chairman, David Packard.)

- In the area of regulation, forcing new technology into old categories is nearly universal because the new is not always seen as new, or the new is seen as a problem, not an opportunity. For example, cable television throughout the country is being treated as a local utility occupying some status resembling, perhaps, electric power. Each local government treats what could be an integrated national information utility on a short-term and somewhat parochial basis. In sharp contrast, Canada and France have adopted policies toward cable that aim to develop a national utility.
- Uncertainties about funding levels for information technology R&D contrast with the needs for stability in budgets or support as a base for long-range research in universities and industry. Examples of such uncertainty include some recent vacillations in funding of certain information technology areas by DOD agencies, particularly DARPA; and the current uncertainties concerning supercomputer research support between DARPA and NSF. (See ch. 3).
- Information technology industries are now combining technologies developed under regulation (as in radio, telephone, and television) with computer technologies basically developed in the market system. The convergence of these two types of technologies creates new regulatory issues dealing with ownership, public versus private control, privacy, and access.

Options for Addressing the Issue

As a core technology, information technology is used by everyone but is not clearly the responsibility of anyone. Yet, given its value to the balance of trade and productivity of U.S. industry, the demands for new, more coherent action have become increasingly strong.[16]

[16] **See, for example, Science Policy Research Division, Congressional Research Service,** *The Information Science and Technology Act of 1981,* **June 1982.**

Option 1: Maintain the Status Quo. The strongest argument for no major change in Federal activity is that the technologies and their effects are highly fluid, and it maybe too early to devise appropriate policy or Government organizations. In addition, some may view coherent, coordinated Federal policy toward information technology R&D as unnecessary or infeasible. The ad hoc coordination currently used has been relatively effective, and attempting more formal coordination or more elaborate national policy could be cumbersome. In addition, pluralistic research funding has the advantage of funding more than one approach to a research topic or problem.

The disadvantage of maintaining the status quo is that we may reduce opportunities to enhance our competitiveness and to use our R&D resources in a more socially productive manner.

Option 2: Improve Monitoring and Coordination. A first step toward coordination of Federal roles would be to provide new mechanisms for the various agencies involved in this area to communicate in a systematic way. Such coordination mechanisms would at least raise the level of attention to information technology R&D issues and provide a forum which could facilitate a common understanding of areas of strength and weakness in Federal support. Congress could designate a formal coordination group with representatives from appropriate agencies involved in information technology R&D. In fact, the first priority of a coordination group could be a report to the Congress, and subsequent hearings, on those areas of strength and weakness. Though DOD would be a major player in such a coordination effort, it is important that it not dominate; the status, needs, and objectives of the civil sector should have an adequate platform.

Other coordination and monitoring steps may also be desirable. To the extent that States play a stronger role in promoting information technology R&D centers, and in using information technology for delivery of services, it may be useful to establish mechanisms whereby States and the Federal Government can cooperate in setting priorities for information technology R&D. Such mechanisms could include a national conference on the intergovernmental research needs in information technology R&D, hearings on State and local information technology R&D needs, and commissioning studies of the needs of State and local governments for improved information technology.

Option 3: Set New National Policy. A more comprehensive alternative is to make a high-level policy commitment to information technology R&D. This could be accomplished by reestablishing an office such as the Office for Telecommunications Policy in the Executive Office of the President, or elevating the responsibilities, status and visibility of the National Telecommunications and Information Administration and the Institute for Computer Science and Technology (ICST) in the Department of Commerce. To complement this action, Congress could establish a lead agency for information technology R&D policy that could devote a substantial amount of high-level attention to the issue. However, the establishment of a lead agency has the disadvantage that that agency's mission may be pursued at the expense of others.[17] Note that in the last several years Congress has been considering various proposals for centralized oversight bodies for information technology policy.[18] Congress may also wish to consider restructuring the basic oversight mechanisms for information technology R&D in the Congress and/or the executive branch.

Finally, it maybe an opportune time to take action on several more detailed issues. The one that is most prominent is software, as discussed in the chapter 3 case study of software engineering. Federal standards for supporting, using, testing, updating and documenting software could add much reliability to Government information systems and consistency to relations between the Government and industry. One mechanism for dealing with these issues is to work through ICST.

Option 4: Establish a New Federal Organization. Congress could create a new organization, transferring to it much of the current dispersed responsibility for information technology and adding new functions. These new functions could include compiling and interpreting information on Federal procurement of information technology, civilian vs. military priorities in R&D, regulatory actions with direct or indirect effects on the technology, the U.S. position in domestic and international markets, social impacts of information technology, high priority issues to be resolved, and recommendations for congressional action. The advantage of such a new organization would be that it would assure that the technology would be visible and explicitly addressed; on the other hand, it could diminish the effectiveness of other organizations that pursue information technology R&D as part of their mission. A new organization could be part of a new "National Technology Foundation," or it could be a freestanding "Institute of Information and Communication."

ISSUE B: Military/Civilian Balance

Relying primarily on DOD for funding of information technology R&D may conflict with the pressing demands of international competitiveness and productivity.

Introduction

The Department of Defense (DOD) has been by far the largest supporter of information technology R&D among Federal agencies. With increasing budgets for R&D in the recent past, DOD is sponsoring a higher proportion of many fields of R&D activity. The dominance of DOD in information technology is perhaps the most striking of all, however; estimates of the proportion of DOD funding range from 70 to 80 percent or more of all Federal funding.[19] In some parts of the field, DOD has sponsored pioneering work which established

[17]See Brooks, op. cit.

[18]See "Institutional Options for Addressing Information Policy Issues," op. cit.

[19]These estimates are based on W. C. Boesman, "U.S. Civilian and Defense Research and Development Funding," Science Policy Research Division, Congressional Research Service, Aug. 29, 1983. Also see ch. 2 for further discussion.

foundations for both commercial and military applications. However, with tightening budgets and growing concern over international competitiveness, the wisdom of DOD's continued dominance of information technology R&D funding is coming into question. Specifically, three questions have surfaced in the course of OTA's study:

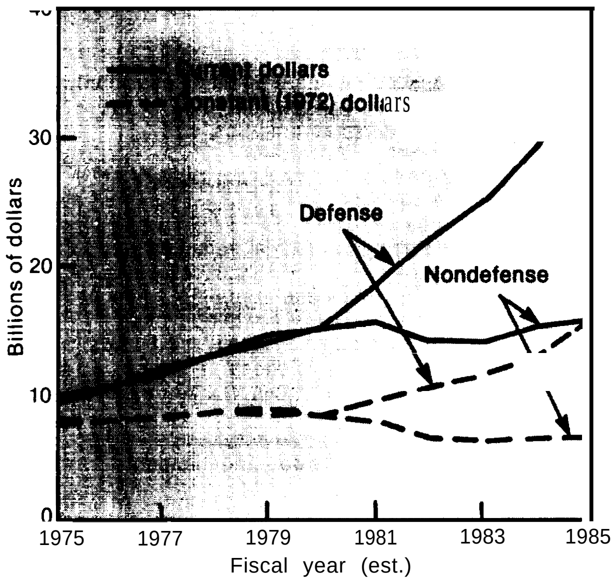
1. Is the military work siphoning off too much talent from civilian applications?
2. Is the military work changing the direction of research in information technology in ways that are disadvantageous for the commercial sector or for the public?
3. Are existing efforts to transfer technology from military to commercial applications adequate?

Dimensions of the Issue

DOD and civilian agency funding of R&D have varied in relative emphasis and roles over the past decades. The issue of DOD vs. civil funding of R&D has received little emphasis since the late 1960s, when DOD R&D was drastically reduced because of a perception that the agency had overstepped its mandate, and because of social concerns about the DOD budget. As shown in figure 50, in the past decade (and particularly during the Reagan administration) DOD funding for R&D of all kinds has risen dramatically faster than civilian agency funding, which has actually dropped in real terms. It can be misleading to use the combined term, R&D, in this discussion; as figure 51 shows, for all fields combined, the dramatic increase has been almost exclusively in development, rather than in basic or applied research.

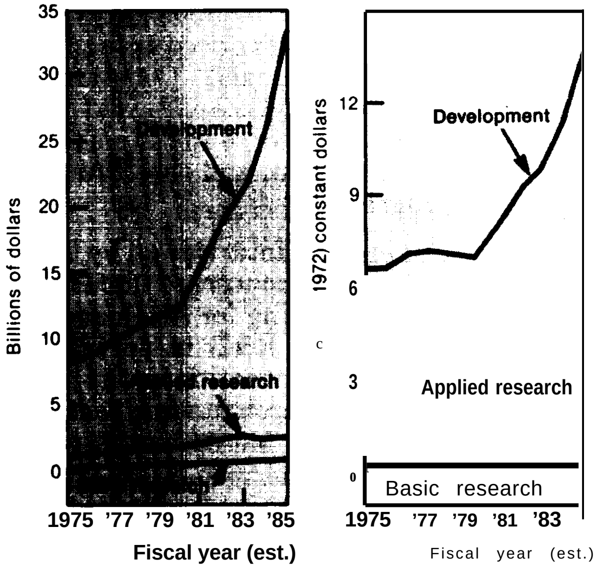
More specifically, DOD support for work in information technology, particularly through the Defense Advanced Research Projects Agency (DARPA), has remained strong and has grown dramatically. As shown in table 49, support for basic research in mathematics and

Figure 50.—Federal R&D Budget Authority for Defense and Nondefense Activities



SOURCE: Division of Science Resources Studies, National Science Foundation "Federal R&D Funding: The 1975-85 Decade, " March 1984

Figure 51 .—Federal R&D Budget Authority for Defense Activities by Character of Work



SOURCE: Division of Science Resources Studies, National Science Foundation, "Federal R&D Funding: The 1975-85 Decade," March 1984

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Table 49.—Department of Defense Funding for Basic Research by Discipline, Fiscal Years 1982, 1983, and 1984 (budget authority In millions)

	Fiscal year 1982	Fiscal year 1983	Fiscal year 1984	Fiscal year 1985
Physics, radiation science, astronomy and astrophysics	76.0	80.9	87.2	96.6
Mechanics, aeronautics, and energy conversion	73.1	79.5	86.3	92.2
Materials	71.5	81.0	82.8	87.5
Electronics	90.0	90.5	97.9	93.7
Oceanography	51.1	50.2	53.4	57.5
Biology and medical sciences	64.9	66.3	79.8	86.7
Chemistry	53.1	58.9	62.0	66.3
Mathematics and computer sciences	83.3	98.8	111.7	124.9
Terrestrial sciences, geophysical research	24.3	29.0	30.8	33.9
Atmospheric sciences	20.8	21.8	25.0	28.2
Behavioral sciences, human resources	33.9	33.6	35.2	36.3
Special studies	—	2.0	—	
University instrumentation	—	30.2	30.0	300
In-house laboratory independent research	54.1	57.5	58.4	67.0
Total	696.1	780.0	839.3	899.9

SOURCE: Leo Young, Department of Defense, presentation to AAAS Colloquium on R&D Policy, Mar. 29, 1984.

computer science grew from $83.3 million in fiscal year 1982 to a planned $124.9 million in fiscal year 1985. In applied research and development, several major projects at DOD have pumped many hundreds of millions of dollars into information technology. These projects include Very High Speed Integrated Circuits (VHSIC); Command, Communications, Control, and Intelligence (C^3I); and more recently the Strategic Defense Initiative (SDI) or "Star Wars" program, and the Strategic Computing program.

Science policy experts interviewed by OTA were almost universally concerned about this resurgence of DOD funding for R&D, and for information technology R&D in particular. Comparing the current situation to the post-War era when DOD research funding was also dominant, they point out that current research is generally much more mission-oriented and, consequently, less productive for nonmilitary uses. Some argue that we are endangering our international competitiveness in the long term by monopolizing the information technology R&D community with defense-related projects. Others point out that it is unwise to have a monolithic source of funding for any area—e.g., certain technical approaches may tend to be ignored —and argue that the current situation desperately calls for a civilian balance to DOD's funding. Despite these strong warnings, however, there is inconclusive evidence that these negative results of DOD's funding are occurring.

For example, in artificial intelligence (AI) the pool of researchers is very small and almost all receive DOD funding. As noted in chapter 3, DARPA and ONR have been almost the exclusive funders of artificial intelligence from the start. Yet, some AI researchers noted during OTA's case study that relatively basic research which could lead to nonmilitary applications-such as intelligent libraries-is being neglected. The assumption that AI R&D funded by DOD is equally applicable to both military and civilian applications is, therefore, under question, although more than anecdotal evidence is needed to assess the problem.

Other controversial topics for the science community in general are export and publication restrictions on scientific and technical information. The dominance of DOD funding of information technology R&D raises the danger that the research will be classified too early to allow nonmilitary users to benefit. This danger is particularly prominent in large scale defense initiatives such as the "Strategic Computing" program. For academic scientists in particular, free information flow is viewed as essential to productivity and to the ethos of science as an international enterprise. Hence, the tension has produced some strong rhetoric. A university association president recently told a gathering of the American Association for the Advancement of Science: "These people feel that any delay or inconvenience for the Russians is worth whatever it costs to us . . . What we are seeing now is not disagree ments among reasonable people; it is ideology without restraint, and it is dangerous to us all. "[20]

Again, however, the extent to which restrictions on information flow have actually been onerous or counter-productive has not been carefully examined. More broadly, except for science policy analysts, most people—at universities, in Congress, or in associations or research groups-have not raised DOD funding as an issue. They maybe comfortable with the current situation, *or* they may be uncomfortable alienating a powerful source of funding.

Part of the reason for infrequent questioning of DOD's dominance in this area is that defense applications for computer-related devices are fascinating problems. One computer columnist noted that state-of-the-art equipment, challenging problems, and the mystique of "secrecy" are powerful lures for computer scientists.[21]

[20]R. Rosenzweig, president, Association of American Universities, address to American Association for the Advancement of Science colloquium on R&D policy, Washington, DC, Mar. 30, 1984. This comment was made when the Department of Defense was considering placing restrictions on the publication of "unclassified but sensitive' research. At the time, the presidents of Stanford, California Institute of Technology, and Massachusetts Institute of Technology "warned the Reagan Administration that their institutions may be forced to stop conducting unclassified research for the Pentagon if they are required to give military reviewers the right to restrict publication of some findings. " (Kim McDonald, "3 Universities Warn Pentagon on Censorship," *The Chronicle of Higher Education,* Apr. 4, 1984, p. 1.) In part in response to this outcry, the Pentagon rescinded itsplan for restrictions. ("White House Decides to Cool Campus Secrecy Issue, " *Science and Government Report,* June 15, 1984, p. 1). See also Albert H, Teich and Jill P. Weinberg, American Association for the Advancement of Science, "Issues in Scientific andTechnical Information Policy, prepared for Office of Special Projects, National Science Foundation, Dec. 28, 1982.

[21]D. Clapp, "While Japan Builds Computers, We're Making Missiles, " *Infoworld,* June 27, 1983.

Options for Addressing the Issue

Option 1: Maintain the Status Quo. While it may be desirable to have a stronger civilian government presence in information technology R&D, some would argue that our national security requirements mandate the current level of DOD involvement, and that it is impractical or unnecessary for civilian agencies to have a balancing involvement.

Potential negative consequences of maintaining the status quo are that we may be compromising international competitiveness, and hence national security, in the long term. The concerns surfacing about DOD's funding of R&D may be early signals of a serious problem, or they could be insubstantial worries. Currently we do not have reliable information to tell the difference.

Option 2: Increase Monitoring and Analysis. The clearest need in addressing the impact of DOD priorities is that it be explicitly addressed and more monitoring and analysis be done. Specific topics in need of monitoring and analysis include:

- Effectiveness and effects of national security restrictions on access to information technology research and devices—especially the exchange of ideas among leading researchers and the ability to use foreign graduate assistants on DOD-related projects.
- Effects of DOD support on the research priorities of leading researchers in the field.
- Transferability of information technology developed for DOD–the ease of transfer, the time lag—compared with primarily commercial development.
- Use of limited manpower in certain fields such as artificial intelligence and software engineering.
- Relation of DOD's requirements for information technology R&D to commercial requirements, and more broadly, the tradeoffs between national security and international competitiveness in this area.

One factor working against explicit consideration of military vs. civilian priorities in

R&D is the fact that Congress is ill-equipped to balance the funding of research among different agencies because the agencies' budgets are independent and handled by different congressional committees. The executive branch is theoretically capable of such considerations, but in practice, as noted above, it also handles agencies' budgets as discrete units. Hence, there may be a need for a new mechanism to weigh R&D goals in information technology from a multiagency perspective. Such mechanisms could include joint congressional hearings, activities of the interagency coordination body discussed in Issue A, and/or a joint study by DOD and a prominent civilian group such as the National Science Board on the relationship of DOD spending to R&D priorities. To be most effective, such a study should probably be tied to subsequent congressional hearings on the issue.

Option 2 does not preclude either of the other options, and hence may be a wise course of action in any case.

Option 3: Bolster Civilian R&D funding. Congress could act to provide a stronger civilian balance to DOD's information technology R&D funding, on the basis of the suggestive evidence of problems, or on the assumption that domination of information technology R&D by one mission agency is unwise. Though such a move would require budgetary increases of several million dollars, many industry and policy experts suggest that the ultimate payoffs in innovation and productivity would be substantial.

Such funding may go beyond some policymakers' notion of appropriate roles for Government. There does seem to be room, however, for more civilian agency funding of "fundamental" (in the sense of being widely applicable and long-term) if not "basic" (in the sense of being disinterested in applications) research in information technology. The funding agency involved would have to be careful that the research community had sufficient manpower to absorb such funds. Some experts have called for a civilian research effort that would mobilize the research community in a way similar to that of the Apollo program—it could be a 5- or 10-year effort toward specific objectives such as uses of computers for education, to aid the handicapped or poor, or other social goals.

ISSUE C: International Competitiveness

> U.S. policies and practices are based on an assumption of unassailable U.S. dominance in information technology R&D, which is increasingly inaccurate.

Introduction

Information technology is an important element of global high-technology trade. As discussed in chapter 7, the efforts of the French, Japanese, and other governments to target information technologies as tickets to future international prosperity attest to that fact. Since the advent of information technologies, the United States has had the lead in development and in global market share. That situation is changing as other advanced nations are increasing their patents in international commerce, as the U.S. balance of trade in information technology begins to weaken, and as the industry becomes more global in character and thus less amenable to traditional methods of governmental control.

Dimensions of the Issue

Stresses of global integration and foreign competition on U.S. information technology R&D policies emerge in several areas. One is the effect on policies promoting development of the R&D base of U.S. industry-manpower, facilities, R&D information and R&D behavior. The issues in this area include:

- Foreign versus domestic high-tech manpower. A large percentage of the graduate students in science and engineering are foreign nationals. It has been a matter of significant national pride that the world comes to the United States for training in science; on the other hand, some have argued that we are investing resources in these foreign students which those that leave then take away to their home country. The value we have placed on science as an international enterprise is under stress as international competition intensifies.

- A related issue is that in those areas that involve national security or commercial secrecy, there are increasing pressures to restrict access of foreign scientists and graduate students. Such restrictions could be a major dislocation in the ethos of the university.
- Restricting the access of foreign scientists to U.S. research may isolate the U.S. research community. Such isolation could reduce the infusion of new approaches and ideas into the R&D process, and thus hinder R&D in the United States.
- Our traditional linguistic chauvinism conflicts with a recognition of the need to translate literature from other countries in this area. Little of the Japanese technical literature, and only somewhat more European literature, is routinely available in English translations.
- Internationalization of the information technology industry is leading to the globalization of R&D. Countries such as Great Britain, the United States, France, and Italy are competing for the location of research centers of the major multinational firms in information technology. Scotland's Silicon Glen is an example. In addition to the competition for multinational R&D facilities, there is growing interest in joint ventures among firms in advanced nations such as Japan, Germany, the United States and France.

Issues also emerge concerning U.S. policies to maintain or improve the current U.S. leadership in information technology R&D and marketing. These include issues related to the structure of the industry, the role of DOD, and the effects of regulation on the industry:

- The individual American corporation in the information technology market may confront foreign government-coordinated, sustained, and supported consortia or consortia of private companies enjoying subsidies and generic research input from their governments.
- The openness of U.S. markets to foreign competition is not met by symmetrical U.S. access to foreign markets. U.S. manufacturers still primarily focus on the U.S. market-the world's largest for information technology. These firms may not be giving adequate attention to developing nations' markets, leaving them largely to other nations. For example, the Japanese are now vigorously pursuing countertrade with the Chinese to exchange mineral resources for Japanese high technology.
- One element of the dominance of DOD in information technology R&D is the potential diversion of talent and resources away from nonmilitary science and technology. The rigid specifications and limited applicability of many DOD-sponsored technologies could skew the development of U.S. information technologies away from those products that are of most use in foreign markets-especially markets in developing nations.
- There is a conflict between the need for free trade and the need to protect sensitive science and technology. The issue is whether U.S. export controls on information technology are unnecessarily excluding U.S. companies from effectively competing for large foreign markets.
- With the development of foreign markets for information technology, concerns arise over the access of small and medium-sized firms to foreign markets. Some feel that where U.S. firms have penetrated foreign markets, the larger firms have dominated trade, to the exclusion of the smaller firms. This is not unusual, since a large majority of manufacturing exports come from large firms. However, with the global integration of the industry, the United States may wish to encourage smaller, innovative firms to seek out foreign trade.
- Promotion of a rational world system for managing the use of information technologies is also important to the long-term leadership of the United States. Though this has long been an area of recognized

importance for U.S. policy, a number of important global standardization issues remain. For example, an increasing issue will be global compatibility of communications systems. The fact that foreign systems are generally run by national governments, while the U.S. system is a market-based system, tends to put the United States in a different, often disadvantageous, position from all the other contenders in international negotiations.

Options for Addressing the Issue

The central issue facing information technology industries is how best to enhance their ability to compete on equal footing with companies from other nations, especially where those companies are strongly supported by government. This problem affects many other industries-from steel to shoes. Continuing debate over the need for an industrial policy flows directly from this issue. As noted in chapter 7, the essential question is not how to imitate the policy strategies of Japan or other countries which appear successful, but to come up with a response that could build on unique U.S. strengths.

Option 1: Maintain the Status Quo. Some would argue that the Federal Government is ill-equipped to become more involved in a fast-paced area such as information technology. The current scheme of activities to promote international competitiveness works well in some respects; the prime role of the Government should be to provide a healthy macroeconomic business climate.

The disadvantage of the status quo is the increasing evidence that the traditional pattern of policies related to international competitiveness does not allow our industries to compete on "a level playing field" with companies from other countries. At present, there is little basis for deciding among options for dealing with foreign competition and its effects on information technology R&D. The relative newness of the threat and the rapid ideological polarization of the industrial policy debate have left the Nation long on conjecture and short on facts.

Option 2: Monitor and Support International Trade in Information Technology, and Related Efforts in R&D. Various measures have been proposed for the support of international trade, and it is beyond the scope of this report to discuss them in detail.[22] A key aspect of trade support is ensuring that foreign markets are open to U.S. industry, and helping U.S. companies to actively seek developing markets for the technology. This could involve increasing the commitment and attention of the U.S. Special Trade Representative, the International Trade Administration, and the Foreign Commercial Service to the needs of information technology firms.

Options more specifically related to R&D include promotion of generic information technology R&D centers in the United States, and close monitoring and evaluation of alternative institutional models-both domestic and foreign-for cooperative research in information technology.

Further, support for international competitiveness in R&D could include establishing mechanisms to monitor foreign technical literature and disseminate translations to American scientists and technologists. Such support could also provide funding for our research personnel to travel overseas for conferences and consultations, and for American students or professors to study overseas. Congress may wish to beef up scientific bilateral agreements and exchange programs.

In addition, it would be appropriate to analyze:

- The amount of foreign purchasing by the Bell Operating Companies that were formerly part of AT&T. As a vast market for information technologies, the behavior of these companies will be critical to the future of the U.S. industry.

[22] See the recent OTA report, *International Competitiveness in Electronics.*

- The extent and type of foreign ownership of U.S. information technology firms and the effects of such ownership on the transfer of information science and technology.
- The career paths of foreign computer and electrical engineering graduate students.
- The extent to which major U.S. information technology firms undertake R&D in foreign countries versus in the United States.
- The effects of joint ventures, countertrade agreements, licensing, and other arrangements on the transfer of U.S. information science and technology.

These information gathering activities would be helpful regardless of the path Congress chooses to take in addressing this issue area.

Option 3: Set National Policy. While there is much we need to know, one alternative is to begin setting a long-term policy on the role of information technology in U.S. trade, and to continue the debate on how the United States might restructure its trade policies to respond to those of Japan and other nations. In addition, the United States could assist the international competitiveness of U.S. firms by developing a national position in international standardization which would take into account the needs of Government, the private sector, and the consumers as well as balance short-term needs with the long-term development of foreign markets.

The United States could establish a more coherent policy on the flow of scientific information, and could establish a review and appeal mechanism for DOD's restrictions on the flow of information and technology.

Options 2 and 3 are not mutually exclusive, and probably make best sense in concert with each other.

Concluding Thoughts

As part of the preparation for this chapter, interviews and workshops were conducted with several dozen experts in science policy and information technology R&D. Box B is a sample of their responses to the question, "What single message would you like to get across to the Congress concerning information technology R&D?" The diversity of these responses indicates the multifaceted nature of issues related to information technology R&D. Their responses are reprinted in box B in order to illustrate the wide-ranging priorities of a group of well-informed specialists, and to provide a different perspective on some of the issues discussed earlier in the chapter.

A common theme in these comments, and in many other discussions of policy in this area, is a drive for perspective: for a long-range view of technological and social changes, and for policies that work together effectively in a wide range of areas.

Indeed, U.S. policy toward information technology R&D, as in many other areas, is partial and incremental. This lack of long-term perspective may in part be inherent in the policymaking machinery; in other cases, policymakers have explicitly assumed that the Government will be most effective when it responds to a mature issue—an issue that has reached a level of public concern where action is clearly called for, and the background of the issue is well understood.

However, the nature of a "core" technology, facilitating major and pervasive social changes, raises questions about the utility of partial and incremental policies. Many of the issues evolving from a core technology are likely to evolve late rather than early, and are likely to be structural-that is, deeply built into the society, and hence very disruptive and traumatic to correct.

not perturb it without a deep understanding of its effect. In particular, as information technology continues to become more pervasive, the government's role must be targeted to a farther horizon, not merely short-term objectives.

The people and the institutions Of this country respond best to challenges when given the latitude to do SO. Please do not legislate on matters of information technology R&D except where you absolutely must.

By its inaction, Congress has allowed competitive companies, providing information technology, to be effectively blocked from the world markets. Legislation and administrative efforts are needed to open the world markets to U.S. competitive companies.

Technological progress is dependent on the existence of a strong educational system at all levels. Without adequate Federal support, the educational system is currently seen to be degrading.

Take vigorous action now to enhance science education for people at all levels and all education. Provide strong support for it.

SOURCE: OTA workshops and interviews.

In response to some of these concerns, various interested parties have called for some kind of prestigious national body which could help sort out issues and lay the groundwork for a long-term perspective.[23] Congress may wish to consider such an option. Although one could be skeptical about creating another commission, other countries have tried variations on this theme with some apparent success in developing long-term perspectives.[24] In the United States, this area of research is rather anemic. For example, the National Science Foundation recently reorganized its Policy Research and Analysis Division to address the short-term needs of the executive branch rather than long-term research on social impacts of science and technology.[25]

Given that such little effort is now being undertaken to understand the long-term effects of information technology, it is difficult to say whether development of such a perspective would be possible in the United States. However, such efforts probably entail little risk, in that any insights derived could help inform policymakers on information technology R&D, and on use of the technology itself. An examination and anticipation of the social and cultural impacts of information technology could at a minimum suggest avenues to explore and monitor, possible options to consider promoting, and identification of potential developments that one might wish to thwart or prevent.

[23]See, for example, J. L. Kirkley, "Backing into the Future," *Datamation*, February 1982, p. 31; M. R. Wessel and J. L. Kirkley, "For a National Information Committee," *Datamation*, 1982, p. 234; David Burnham, *The Rise of the Computer State* (New York: Random House, 1983). For a discussion also see OTA, "Institutional Options for Addressing Information Policy Issues," op. cit.

[24]See Telecom Australia, *Telecom 2000: An Exploration of the Long-Term Development of Telecommunications in Australia* (Melbourne, Australia: Australian Government Printing Unit, 1975); and Nora, S. and A. Mine, *The Computerization of Society* (Cambridge, MA: MIT Press, 1980).

[25]See National Science Foundation, Division of Policy Research and Analysis, "Program Announcement and Solicitation," January 1984.