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ABSTRACT

Presented are nine working papers prepared for the National Science Foundation as one means of assisting the Office of Science and Technology Policy in preparing the administration's "Annual Science and Technology Report to the Congress, 1982." The papers explore aspects of three broad themes central to the administration's science and technology (ST) policies and strategies for their implementation: (1) optimizing use of limited resources for research and development (R&D) so that ST can be used more effectively to achieve national goals; (2) developing a set of equitable and consistent guidelines, within the administration's overall ST policy, for dealing with the generation, organization, and dissemination of ST information; and (3) encouraging implementation, by the private sector, of new technologies that can increase the productivity and international competitiveness of U.S. industry. Papers (each preceded by an abstract) focus on: international cooperation in science--U.S. role in megaprojects; trends in collective industrial research; impact of increased defense R&D expenditures on the U.S. research system; training and utilization of engineering technicians and technologists; national security controls and scientific information; issues in ST information policy; legal and regulatory implications of the video telecommunications revolution; trends in computers and communications--offices of the future; and fostering use of advanced manufacturing technology. (JN)

EMERGING ISSUES IN SCIENCE AND TECHNOLOGY, 1982

A Compendium of Working Papers for the National Science Foundation

National Science Foundation

Contents

Preface

In enacting the National Science and Technology Policy, Organization, and Priorities Act of 1976 (Public Law 94-282), the Congress specified, in a declaration of principle, that the development and implementation of strategies for determining and achieving the appropriate scope, level, and direction of U.S. scientific and technological efforts should involve a wide range of participants from both the public and the private sectors.

In keeping with that commitment, and as one means of fulfilling the National Science Foundation's responsibility to provide primary assistance to the President's Science Advisor in the preparation of the *Annual Science and Technology Report to the Congress: 1982*, NSF convened a series of ad hoc panels of experts from Government, industry, and academia during 1982. Those panels explored the policy implications of a number of current and emerging issues in science and technology that were selected by the staff of the National Science Foundation in consultation with advisors from both inside and outside of Government.

The panels' deliberations are summarized in the nine working papers in this compendium. As anticipated, they were useful to the staff of the NSF Office of Special Projects in assisting the Office of Science and Technology Policy with the preparation of the President's *Annual Science and Technology Report to the Congress: 1982*. Since the papers also delineate an important set of policy issues on the national agenda, NSF is publishing them separately to stimulate public discussion about the roles science and technology can play in contemporary American society. Although all of the papers were reviewed for technical accuracy, the views and perspectives they express do not necessarily reflect official policy positions of the U.S. Government or the National Science Foundation.

Edward A. Knapp
Director
National Science Foundation
October 1983

Introduction

The nine working papers in this compendium, like the set published in 1982,[1] were prepared for the National Science Foundation as one means of assisting the White House Office of Science and Technology Policy with the preparation of the President's *Annual Science and Technology Report to the Congress*. They explore particular aspects of three broad themes central to the Administration's science and technology policies and the strategies for their implementation, as described in the most recent *Annual Report*.[2] These themes are:

- Optimizing the use of limited resources for research and development (R&D) so that science and technology can be used more effectively to achieve national goals;
- Developing a set of equitable and consistent guidelines, within the Administration's overall science and technology policy, for dealing with the generation, organization, and dissemination of scientific and technical information; and
- Encouraging implementation, by the private sector, of new technologies that can increase the productivity and international competitiveness of U.S. industry.

The compendium papers do not aim to provide detailed analyses of all relevant issues. Indeed, since the policy context for most of these issues is in a state of considerable flux, attempts at such analyses run the risk of becoming rapidly dated. Nor do the papers weigh advantages and disadvantages of all possible policy options. Rather, each is intended to identify and discuss significant national issues in science and technology that are either currently on the policy agenda or likely to emerge in the near future.

Optimizing the Use of R&D Resources

The first two papers in the compendium—*International Cooperation in Science: The U.S. Role in Megaprojects* and *Trends in Collective Industrial Research*—explore the policy aspects of two types of cooperative institutional arrangements intended to increase the effectiveness of the resources available for the conduct of R&D. The third paper—*The Impact of Increases in Defense R&D Expenditures on the U.S. Research System*—examines some probable effects on research priorities, particularly in universities, of the Administration's commitment to strengthen the Nation's defense capabilities. The fourth paper—*Training and Utilization of Engineering Technicians and Technologists*—raises questions about the adequacy, in both quantitative and qualitative terms, of the workforce required to support the activities of professional scientists and engineers.

International Cooperation in Science: The U.S. Role in Megaprojects

The context within which international cooperative scientific activities takes place is considerably different from what it was 20 years ago. During that era, the resources for conducting scientific research in the United States—particularly basic research—were relatively unconstrained, and the United States enjoyed preeminence in virtually all scientific fields. In the present environment, where the scientific capabilities and achievements of several other countries are roughly comparable to our own, pursuing research projects within an international division of labor framework has an obvious appeal. This is particularly true for so-called "megaprojects;" that is, projects requiring extensive staffs, complex managerial arrangements, and large budgets.

The Reagan Administration has placed a high priority on international cooperative projects that can augment limited U.S. resources and yield benefits to U.S. science. So, for similar reasons, have the governments of several other industrialized countries. At the Versailles Economic Summit in June 1982, a Working Group was established to consider common opportunities, problems, and challenges associated with science and technology. A draft report, released in March and considered at the Williamsburg Economic Summit in May, includes proposals for 18 cooperative science and technology projects, many of which qualify as megaprojects.

The paper on international cooperation in science reviews some of the potential benefits, both direct and indirect, that can be derived from successful international cooperative projects. The most obvious of these benefits is improved economic efficiency. However, financial advantages are often supplemented by the promise of enhanced access to intellectual resources and unique facilities that are only available abroad, and possibly by important gains in the innovative process itself.

In an international setting, individual governments almost always have multiple policy goals and objectives for international cooperative projects. These can lead to difficulties that need to be weighed against the potential benefits to be derived from collaboration. In addition, countries often have differing rationales for, and rankings of, goals and objectives for scientific cooperation. For that reason, a country's overall political culture may be a more important determinant of its science policy—and therefore the ways in which it will enter into a cooperative venture—than any objective scientific benefits that may derive from cooperation.

The paper argues that the most difficult issue confronting effective U.S. participation in megaprojects is in identifying specific future opportunities for effective cooperation. To make appropriate decisions about such opportunities, information must be available regarding the scientific capabilities of countries with which the United States could conceivably cooperate, and the priorities that are likely to be attached to the development and deployment of those capabilities by the respective nations. Unfortunately, such a systematic knowledge base does not exist.

Trends in Collective Industrial Research

One of the key strategies adopted by the Reagan Administration to implement its science and technology policy is to encourage and facilitate cooperative R&D activities among different types of institutions in the United States. Interest in developing cooperative modes has been heightened because of both the rising costs of R&D and the desirability of improving the links between institutions with vested interests in different portions of the R&D spectrum, ranging from basic research to commercialization.

University-industry research collaboration has been the most highly publicized of these cooperative modes. Additionally, there appears to be a trend toward new cooperative arrangements among industrial firms, some of which also involve support for university research and education.

There have been numerous examples in the past of two or more companies in a particular industry establishing a relationship to engage in technical activities with no formal commitment to joint commercial exploitation. Such joint ventures have often been established through trade associations. Within the past decade, and particularly the past 4 years, cooperative industrial structures have been established that differ from these older arrangements in at least three respects:

- First, their levels of funding are considerably larger;
- Second, several include cooperation with and/or assistance to universities among their objectives; and
- Third, they are based on industrywide concerns about decreasing market shares and increasing foreign competition.

The paper on industrial research cooperation examines the operational characteristics of several collective industrial research arrangements, focusing particularly on four of the newer associations—two in the energy sector, and one each in the chemical and semiconductor industries. The underlying objective of all four groups is to accelerate the pace of technical change either through increasing the number of technically trained people available to the industry, or by conducting research in targeted areas, or both. However, the origins and goals of each group also reflect industry-specific characteristics such as competitive structure, degree of regulation, capital requirements, manpower needs, and relevant antitrust restrictions.

The paper considers the longer range implications of large-scale industrial cooperative research for industry, universities, and

Government. It concludes that although the funds available for collective research among firms within an industry are likely to remain small relative to the total expended for R&D by the industry, the focused character of the available collective resources could have a significant impact on industrial—and university—research directions.

Possible Government actions to encourage the growth of collective industrial support include: (a) offering indirect financial incentives to industrial firms for collective support to universities, and (b) providing focused support to universities to strengthen their capabilities for cooperation in areas of interest to collective industrial groups. These actions would be broadly consistent with the Reagan Administration's policy of providing indirect incentives rather than direct subsidies for industrial R&D, while concentrating Federal resources on strengthening the capability of universities to conduct fundamental research in areas of importance to the Nation.

The Impact of Increases in Defense R&D Expenditures on the U.S. Research System

The third paper in the compendium explores the potential impacts on the U.S. research system, particularly on universities, of the accelerated growth of the defense R&D sector relative to the civilian sector. Department of Defense (DOD) support of university basic research during the 1950s and 1960s provided the foundation for much of the growth and development in the university research system. This support also laid the groundwork for such important technological innovations as computers and lasers. This paper concludes that, overall, the present defense buildup is likely to have a far less significant effect than in the past on university research. The Department of Defense's budget for research, development, test and evaluation (RDT&E) will increase by an estimated 78 percent between fiscal years 1981 and 1984, while all other Federal R&D expenditures will decrease by an estimated 12 percent. However, whereas the growth in the basic research component of the defense budget is relatively small, the basic research components of the other principal agencies that support universities have been relatively well insulated against the general decrease in civilian R&D budgets. There could, however, be substantial impacts on specific scientific disciplines of particular interest to DOD as shifts in research priorities result in changing support allocations.

The paper argues that DOD's increased support for graduate students in particular fields of science and engineering—through both fellowships and research assistantships—could have a substantial effect on the entire U.S. R&D system, including the university and industrial sectors. This augmented support is intended, in part, to help resolve the problem the armed services have been experiencing recently in recruiting and retaining engineers as well as scientists in several critical subspecialties. Despite DOD's student support programs, the pool of highly qualified scientific and technical personnel in critical fields is unlikely to be sufficient to meet the demands of both the defense and the nondefense sectors during the next few years. For that reason, there may well be a continuing and increasing competition for scientific, and particularly, engineering talent. In view of the current defense buildup, this competition could have a deleterious effect on both universities and nondefense industries, and thus on the overall science and technology base required to maintain long-term U.S. national security.

Training and Utilization of Engineering Technicians and Technologists

Concerns about both the quantitative and the qualitative adequacy of scientists and engineers in the defense and civilian sectors have been widespread for a number of years. Factors that threaten to undermine the quality of U.S. engineering education have also been examined in detail. Likewise, deficiencies in secondary education have been widely advertised and considered at length in several recent reports, most notably those of the National Commission on Excellence in Education and the National Science Board's Commission on Precollege Education in Mathematics, Science, and Technology. However, the quantitative and qualitative adequacy of the technicians and technologists required to support scientific and engineering activities has received little comparable national attention.

A primary objective of this paper is to place questions regarding the training and utilization of these support personnel within the broader contextual issue of assuring that the overall scientific and technical workforce is adequate to meet both present and long-term national goals. Three potentially serious problems associated with technician training and utilization are identified. First, there is a considerable mismatch between the types of training and skills that have been acquired by the existing technical workforce and the skills demanded by industry. In particular, many technicians, as well as engineers, appear to be underutilized. Second, there are serious pressures on technician training institutions, including community colleges and proprietary schools, that are broadly similar to those currently plaguing engineering schools. These pressures include chronic faculty vacancies and lack of state-of-the-art instructional apparatus. They threaten to erode the quality of the educational offerings of the institutions. Third, reliable information about the supply and demand for technicians and technologists is inadequate. These inadequacies are exacerbated by the fact that the job skills required for technicians in particular industries are often poorly defined. Thus, it is difficult to place questions about technician training and utilization within the context of national scientific and engineering manpower goals.

The paper suggests that industry has a central role to play in clarifying training and utilization opportunities for engineering technicians and technologists. However, new cooperative initiatives involving industry, education, government at all levels, and professional associations appear to be essential if the national need for an adequate technical workforce is to be met.

Scientific and Technical Information Policies

The major problems explored in the next two papers in the compendium—*National Security Controls and Scientific Information* and *Issues in Scientific and Technical Information Policy*—have emerged as compelling policy issues because of their relationship to two of this Administration's major goals for science and technology: (a) relying on advanced technologies to strengthen the Nation's defense capabilities; and (b) delineating more clearly the appropriate roles and responsibilities of the public and private sectors with respect to science and technology activities. Issues associated with scientific and technical information are unusually complex from both a technical and a policy perspective because they pervade a variety of policy spheres often far removed from science and technology.

National Security Controls and Scientific Information

One of the byproducts of the Administration's overall policy of enhancing the Nation's defense posture has been a well-publicized debate focused on the Government's apparent willingness to restrict the dissemination of scientific information to foreign nationals and to limit their participation in R&D activities in an attempt to stem the outflow of U.S. military technology and sensitive information. Concerns and uncertainties about policy in this area have become a potential source of tension that could undercut the efforts made by the Department of Defense during the past few years to reestablish closer ties with the university research community.

The issues posed by the Administration's general policy of increasing control over the dissemination of scientific and technical information involve a fundamental value conflict between basic national security concerns and the need to preserve academic freedom. This paper argues that the resolution of these issues requires a clearer understanding of whether the various controls now in use, or under consideration, will be effective in preventing a loss in this Nation's technological lead over the Soviet Union, and whether those controls can be implemented without imposing unacceptable economic, administrative, scientific, or political costs to the American scientific enterprise.

The debate over the control of scientific information has both substantive and procedural dimensions. The Government acknowledges that whereas the Soviet Union has acquired a great deal of advanced American technology by both open and covert channels, very little has come through such normal modes of scientific communications as university graduate courses, laboratory visits, conferences, and publications. However, the Government is concerned that in the future the Soviets will more consciously exploit the openness of the U.S. system of research and graduate education to gain access to advanced defense-related technology.

The university community, while conceding that the application of existing controls has as yet created few real problems for research or education, is concerned that the vaguely defined, open-ended character of that system could cause problems in the future. The terms of the Export Administration Act, for example, could be interpreted as restricting dissemination of scientific information directly applicable not only to military technologies, but also to so-called dual-use technologies. More seriously, there is concern that more stringent restrictions could be applied to the dissemination of a much broader class of scientific information in an attempt to limit the outflow of technologies to U.S. economic as well as military competitors.

The paper reviews some of the fundamental issues that need to be addressed to clarify the terms of the current debate and move toward a resolution. These issues include defining "national security," the geographical scope of controls, what technologies are to be controlled, and what types of scientific information and scientific activity underlying those technologies are to be controlled. Procedural questions dealing with what forms controls should take and how they are to be adapted, enforced, and modified also need to be addressed. Regarding this latter set of questions, the paper concludes that broadly drafted rules of general applicability are likely to generate more serious frictions between the Government and the research community than those that can be defined on a case-by-case basis and tailored to a particular setting or a particular technology. If broader rules are used, the burden for making decisions about their applicability falls heavily on the research community; with narrower restrictions, those decisions are either in the hands of the Government and/or are negotiable in advance.

The paper argues, finally, that an enhanced dialogue between the Government and the scientific community and an increased reliance on contractual restrictions in federally sponsored research offer the greatest promise for balancing the conflict between maintaining national security and preserving maximum scientific openness.

Issues in Scientific and Technical Information Policy

The control of scientific information for national security purposes is only the most visible of a host of complex issues on the national agenda that are associated with scientific and technical information policy. This paper suggests that policymaking concerning scientific and technical information cannot be considered in isolation. First, since the generation and dissemination of scientific and technical information is clearly an integral part of R&D policy, decisions in this area should be closely linked with R&D priorities and management. Second, scientific and technical information policy is but one aspect of the much larger domain of information policy and management. These linkages result in complexities in delineating and resolving science and technology information policy issues.

Two sets of issues are reviewed in the paper: those having to do with access to scientific and technical information, and those associated with the economics of that information. Both sets of issues have become increasingly urgent as a result of the rapid growth and convergence of computer and communications technologies.

Access issues include the perennial problem of how to protect the confidentiality of personal data gathered as a result of research activities such as statistical surveys, psychological examinations, and epidemiological studies. A closely related issue has to do with protecting proprietary rights to commercially valuable scientific information. Traditional patent, copyright, and trade secret copyright laws may, in the case of computer software, provide inadequate ownership protection, and thus discourage industry from making adequate investments in software development. By comparison, in such rapidly developing fields as biotechnology that depend heavily on progress in basic research, the overzealous protection of proprietary rights can limit scientific communication and thereby inhibit the development of the field.

A final access issue is concerned with possible U.S. responses to restrictions imposed by several other nations on the flow of information across their borders. The paper suggests that while there are many good reasons why the United States should not emulate these restrictive policies, it is important that U.S. foreign policies deal with them more effectively. For that reason, the economic and/or cultural rationale underlying those policies needs to be more clearly understood.

Economic issues associated with scientific information have assumed particular importance because of the Reagan Administration's policy of returning responsibility for the development of commercializable products and services to the private sector. One unresolved problem is how to set a price on information collected or generated by the Federal Government that recovers a reasonable fraction of the cost, while assuring equitable access to that information. A closely related problem has to do with protecting the private sector from unfair competition by the Federal Government, while assuring that the quality and accessibility of data bases that have been the responsibility of the Federal Government are maintained. Central to the resolution of these issues will be finding ways to place a monetary value on information products and services, and to determine which types of information serve the broad public interest and which serve narrower interests more appropriate for private sector commercialization.

The paper reviews the debate on these issues, highlighting the major arguments in favor of, and opposed to, further limiting the Federal role in generating, organizing, and disseminating information. It concludes that there is a pressing need for a systematic reassessment of pricing policies for Federal information services, particularly since those policies differ considerably among Government agencies. More generally, the paper suggests that authority and responsibility for dealing with scientific and technical information issues within the Federal bureaucracy need to be more clearly defined. Concurrent with such a review and possible restructuring of Federal authority and responsibility in this area, awareness of scientific and technical information policy issues needs to be enhanced among Federal R&D policymakers. Likewise, representation of U.S. interests in scientific and technical information ought to become a more conscious element of our foreign policy.

Encouraging the Implementation of New Technologies

The three papers that constitute the final set in the compendium—*Legal and Regulatory Implications of the Video Telecommunications Revolution, Trends in Computers and Communication: The Office of the Future*, and *Fostering the Use of Advanced Manufacturing Technology*—are explicitly concerned with the effects of emerging technologies on public policy, and, reciprocally, with economic, social, and political factors that affect the adaptation and implementation of promising new technologies. Understanding these factors is particularly important in view of the Administration's policy to encourage the accelerated commercialization of high-technology products and services and by so doing to increase the productivity and international competitiveness of American industry.

Legal and Regulatory Implications of the Video Telecommunications Revolution

This paper presents a particularly timely case study in the way new technological capabilities can challenge the rationale underlying a long-standing public policy.

The basic premise for the Communications Act of 1934, which still serves as the centerpiece for Federal regulation of broadcasting and cable, was the presumed scarcity of communications frequency bands in the electromagnetic spectrum. This scarcity assumption was entirely appropriate in 1934 when foreseeable communications technologies rested on broadcasting within a relatively limited region of the spectrum. In view of the assumed scarcity of frequency space, the framers of the Communications Act agreed that a totally free market would result in a highly chaotic situation that would in turn distort the development of the broadcast industry. The Act therefore sanctioned regulated monopolies by directing that specific frequencies should be licensed to a limited number of radio (and later television) stations. In return for the privilege of limited competition, the activities of licenscd stations were to be regulated in the public interest by a new agency—the Federal Communications Commission (FCC).

During the past decade, new communications technologies have all but made moot the scarcity assumption on which the 1934 Communications Act rests. This is particularly true for video telecommunications, where the advent of cable, microwave, and satellite communications technologies has led to a phenomenal increase in the number of interference-free broadcast channels available in a particular geographical region. The paper argues that, as a result, the former Government-sanctioned and regulated regime within which the broadcast industry developed is in the process of becoming a competitive, unregulated regime.

The paper considers four broad policy issues raised by this transition from a relatively uncompetitive video market to one characterized by competition and abundance:

- How should entry into the video marketplace be regulated—for example, how active should the Federal Government be in licensing, franchising, and technical standard-setting?
- To what extent and by what means should video content be regulated—for example, should the Fairness Doctrine requiring a balance of presentations on controversial issues be maintained in a nonmonopoly environment?
- To what extent should the Federal Government encourage a truly competitive video market—for example, what should it do about concentration, cross ownership, and joint ventures among media operations?
- What dangers to democratic rights may be posed by the video telecommunications revolution—for example, invasion of privacy and the widening of information gaps between rich and poor?

All four issues involve complex economic and social factors. The paper posits that the most likely scenario for their resolution during the remainder of the decade is a shift in both the substantive focus and the locale of video regulatory action. According to this scenario, emphasis will move from a concern with licensing standards toward maintaining a competitive market. Since policy debates and directives would then be carried on within an antitrust framework, the locale of regulatory activity would most probably shift from the FCC to the Congress and the courts.

The regulatory framework for video telecommunications, involving as it does the interplay of a number of uncertain economic, social, and technological factors, is changing as the available technologies evolve. The extent to which any individual new technology is ultimately adapted and implemented for successful commercial use will depend in large measure on the development of that regulatory framework.

Trends in Computers and Communication: The Office of the Future

According to the *Annual Science and Technology Report to the Congress: 1982*, the Administration intends to focus its R&D support more sharply than in the past in the service sector, in recognition of its growing importance to the U.S. economy.[3] Recent technological advances have considerable potential to increase productivity in the service sector. In particular, the use of computers linked by communications networks could lead to dramatic changes in the ways that office functions are performed and, therefore, in the ways that offices—and the larger institutions they serve in both public and private sectors—are organized and managed. The relatively recent introduction of free-standing word processing facilities has already led to some changes in office practices, although not, as yet, to the dramatic gains in white collar productivity that many experts had foreseen. One probable reason is that word processors have often been regarded primarily as labor-saving devices and introduced with little or no advanced ɔlanning about how to reorganize an office ɔr redefine tasks to make optimum use of :heir capabilities.

This paper describes a range of currently ɑvailable technologies, all of which are likely to ɔe implemented in the office of the future. These include word processors with substantial stand-alone capabilities that can :ommunicate with one another via telephone inks; facilities to handle electronically all :orrespondence within an organization as well as a good deal of communication ɔetween organizations; and teleconferencing acilities to replace face-to-face meetings. The ɔpportunities offered by these innovations o develop entirely new approaches to ɔrganization, management, and control ɔromise dramatic gains in service sector ɔroductivity. However, the fact that behavioral ınd organizational factors are crucial to the mplementation of computer-based office echnologies may be a principal reason for heir unexpectedly slow acceptance in the narketplace.

The paper discusses some of the factors hat have impeded the implementation of hese technologies. It also explores some of he implications for the nature and organi:ation of office work in the future, and for he skills that will be demanded at various evels within organizations if and when these echnologies become commonplace. The ɔaper concludes by identifying a number of :conomic and social problems that are likely o emerge if office automation proceeds as ınticipated, while noting that the nature and everity of these problems will depend on he pace of implementation. Whatever that ɔace may be, the demands on industry and ɔn educational institutions to define and to ɔrovide the technical skills required of future ɔffice personnel are likely to be particularly ɔressing.

'ostering the Use of Advanced Ianufacturing Technology

'he adaptation and implementation of vailable and emerging technologies for ommercial use are particularly important ɔ manufacturing industries. During the past ecade, several new technologies have made ossible fundamental changes in manufacıring processes that could lead to significant enhancements in the quality of manufactured products and to an overall growth of productivity and international competitiveness in the U.S. manufacturing sector. Substantial contributions were made by American engineers to the development of many of these innovative technologies, including robotics, computer-aided manufacturing, group technology, and flexible manufacturing systems. Yet the United States has lagged behind other industrialized countries in the diffusion and implementation of advanced manufacturing systems. This lag has led, in part, to the erosion of our international competitive position.

This paper argues that most analyses of the relative failure of U.S. industry to incorporate advanced process technologies have been flawed by an almost exclusive concern with macroeconomic factors. In contrast, factors that determine whether and how these technologies are implemented at the factory level have been largely ignored. Advanced process technologies ought to be regarded as complex sociotechnical systems rather than as pieces of hardware. It follows that their implementation into manufacturing processes often involves major changes in corporate strategies, organizational design, and human resource requirements.

For example, implementation of a robotics system cannot be carried out effectively by simply replacing human workers with machines. Rather, making effective use of robotics may require that entire production processes be redesigned and new types of tasks assigned to workers on the factory floor. Such modifications most often require that workers be retrained in new skills. Equally important, successful implementation of an advanced robotics system may require the active participation of workers in operational decisionmaking, with significant implications for corporate management practices. Thus, implementation of these and other advanced manufacturing technologies involves interactions among different functional units within a firm, with effects that may be radical rather than incremental.

The paper argues that current efforts to encourage the implementation of advanced manufacturing systems in U.S. industry are probably inadequate, given the inherent difficulties in the technology transfer process.

Federal efforts have been uneven, particularly since much of the Federal R&D effort is mission oriented. Universities, while reasonably active in the R&D underlying advanced manufacturing technologies, have largely ignored dissemination and implementation problems. The paper concludes that a systems orientation by both Government and private industry will be required if U.S. industry is to take full advantage of the promise of these new technologies.

While the last set of these papers deals explicitly with policies to accelerate the implementation of new technologies, each of the other papers in the compendium deals with parts of the broader question of how the United States can make more effective use of its superlative capabilities in science and engineering to achieve its national goals. As all nine papers make clear, attainment of this broad objective will require, in the words of the *Annual Science and Technology Report to the Congress: 1982*, "...a strong partnership among Government, industry, and academia, with each understanding its responsibilities, assuming them to the fullest, and carrying them out completely."[4]

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International Cooperation in Science: The U.S. Role in Megaprojects

Abstract

A promising option for reducing the strain on American scientific resources is cooperation with other countries in those international activities that demand big staffs, complex managerial arrangements, and large budgets—the so-called "megaprojects." In the future, these "big science" efforts increasingly may be pursued within an international division of labor framework emphasizing the identification of particular areas of expertise or concentrations of special facilities that provide unique opportunities for the U.S. scientific community. The greatest potential benefit from such cooperation is improved economic efficiency, but the financial advantages of joint action are supplemented by the promise of important gains in the innovation process itself and by the possibility that political good will among the participants will be enhanced. But scientific cooperation on a large scale is not without its obstacles and constraints. Bureaucratic inertia and resistance must be overcome, sufficient planning capabilities must be linked to the cooperative venture, and systematic evaluation of the anticipated and realized costs and benefits of the project must take place. Moreover, the fragmented and largely incoherent approach used to date in formulating and implementing cooperative scientific programs must be modified. At least four sets of policy issues must be faced and overcome: choice of areas of cooperation, choice of partners, choice of organizational and managerial mechanisms, and choice of funding arrangements. Resolving these issues appears to depend upon the ability to develop a data base defining the international division of labor in science, to generate greater coordination among the various national science organizations, and to be more explicit about the funding levels for cooperative projects.

Introduction

The more than 20-year era in which the United States was able to dominate the global science and technology arena by pursuing an aggressive, broad-front assault on the entire menu of scientific and technological alternatives appears to be over. Several factors have contributed to the end of American dominance of international science and technology.

First, the long-term condition of reduced rates of economic growth, combined with inflation, has constrained the investment of funds in both the human and the physical resources available for scientific and technological activities. For example, as early as 1981, analysts of the U.S. research and development (R&D) system were observing that a "fundamental turning point" had been reached with regard to Federal funding. Nondefense R&D has been faced with tighter budgets, and many initiatives have been either cancelled or deferred.[1]

Second, U.S. leadership in scientific and technological fields has given way to shared, or even lost, leadership as the Western democracies and other states have reconstructed and developed in the postwar period. This is particularly the case with regard to the OECD (Organization for Economic Cooperation and Development) economies, but increasing competition also comes from a number of Communist countries and a few industrializing less developed nations.[2] The OECD states, especially West Germany and Japan, have expanded dramatically their intellectual and productive capabilities since World War II, and these states have gone further than the United States in exerting a measure of centralized control over the formulation and implementation of science and technology policies. As a consequence, they have become much more competitive in international trade.[3]

Third, the science and technology policy priorities of most OECD states, including the United States, have undergone substantial changes over the past two decades. In this country, the pressure to reestablish economic growth rates and to create employment opportunities has meant that industrial innovation increasingly has come to be seen as the most crucial, and most ignored, nondefense science and technology priority.[4] Compare this orientation with the 1970s focus on such priorities as environmental protection or social development and services.

Recognition of these limitations, implicit in actions of the Federal Government for some time, now has been officially acknowledged. For instance, George A. Keyworth, Director of the Office of Science and Technology Policy (OSTP), has said of the emerging difficulties facing American scientific and technological initiatives:

> As I have stated on other occasions, there are a number of good reasons why we cannot expect to be preeminent in all fields, nor is it necessarily desirable. The idea that we can't be first across the spectrum of science and technology is not simply a function of our current economic situation. The fact is that immediately after World War II this country was alone in developing and pursuing technology. Since then the rest of the world has been catching up—with much help from us.[5]

Taken together, these factors have made international cooperation in science and technology an especially attractive option. Not only can joint action reduce the strain on American resources, but the capabilities of other advanced, industrialized countries, and occasionally those of underdeveloped countries, are welcome assets in the pursuit of the benefits of science and technology. Indeed, President Reagan himself has cited the desirability of such efforts and the need for this country to identify the "most fruitful areas of cooperation."[6]

International collaboration in science and technology encompasses a variety of substantive activities. These range from support of military and political alliances through the use of more applied R&D, to very informal linkages among members of the global scientific community concerned with the advancement of knowledge and the most basic aspects of research. Such activities are pursued through many different organizational and managerial arrangements, including bilateral or multilateral governmental relationships, or the use of international organizations. Many different participants perform a variety of roles in these cooperative ventures. The most significant actors are national governments, private corporations, and universities.[7]

There appears to be some consensus in the American scientific and engineering community that one of the most promising opportunities for U.S. involvement is in international "megaprojects," or so-called "big science."[8] These are projects in such areas as high-energy particle physics, outer space exploration, or geodynamics research that require extremely elaborate equipment and facilities and large teams of professionals—requisites that typically demand complex organizational and managerial mechanisms, usually multilateral in character, and a variety of participants, including substantial inputs from the private sector and universities.[9]

A good example of a megaproject is the European Center for Nuclear Research (CERN) plan to build a new particle accelerator as part of its high-energy physics program. This large electron-positron (LEP) storage ring is designed to speed subatomic particles around a circular tunnel 16 miles long (by comparison, the Fermi National Laboratory's facility in Illinois is 4 miles in length). The first phase of the new CERN accelerator is estimated to cost some $610 million, and the second phase about $120 million more. The final cost might be as high as $1 billion. Perhaps 250 physicists, from both Western and Communist scientific establishments, would be involved in the effort. For the United States, the cost of participation is projected to be some $20 million. If it is approved, the LEP would represent the largest American commitment of this kind. Given constrained domestic finances, the LEP proposal has been termed an "acid test" of U.S. involvement in cooperative international science projects.[10]

Uncertainties about the size, scope, and skill mix of megaprojects like the LEP are the greatest incentives for American involvement and, at the same time, the most significant sources of opposition to international cooperation. On the one hand, supporters of collaboration argue that the cost of U.S. unilateral action in big science projects increasingly is prohibitive. Moreover, many proponents of cooperation have been critical of the traditional "pork barrel" way in which some funds have been allocated among U.S. scientists in big science areas. On the other hand, opponents of cooperation stress the underfunding of American projects, and they ask difficult questions about how the costs, risks, and benefits of collaboration are to be determined and distributed among participants.[11]

Faced with such sensitive and controversial issues, U.S. policymakers have been searching for a more systematic way to choose appropriate targets of opportunity. Increasingly, the Reagan Administration is approaching such choices in the context of an "international division of labor" framework. That is, there is an attempt to identify special areas of expertise, concentrations of particular skills or equipment, or other characteristics of the global scientific infrastructure that pose attractive opportunities for U.S. involvement. As OSTP has argued:

> We must now think in terms of an international division of labor, where achievements in one place can complement those in another. Through cooperation with other developed nations, we can achieve a more efficient distribution of the burden of scientific and technological research on a world scale and provide access for U.S. scientists to special or unique facilities abroad that would be prohibitively costly to reproduce at home.[12]

Although hardly a new idea—it has been suggested for years that greater international use should be made of certain national facilities—the use of this approach as a decision framework still is new to this country. Nevertheless, enough is known to make it clear that an international division of labor orientation has some key advantages. First, it incorporates the requisite of budgetary discipline into the choice of appropriate targets of opportunity. Second, because it focuses attention on the unique resources of other societies, it holds the promise of simplifying somewhat the process of making decisions about potential partners, institutional mechanisms, and areas of cooperation. Third, it makes explicit a criterion, economic efficiency, by which choices can be made. Clearly, defining operational evaluative criteria appears to be a very important requirement when attempting to assess such complex scientific undertakings as megaprojects.

The purpose of this paper is to ask: What issues are likely to confront the division of labor approach to American participation in scientific megaprojects? And how can these issues be resolved? Following a background discussion of the opportunities, difficulties, and conditions for success in international scientific cooperation, the emerging issues likely to pose obstacles for U.S. involvement in science megaprojects are outlined. Finally, some policy options for contributing to the resolution of these issues are delineated.

Background

The substantial opportunities and benefits associated with international cooperation in science always must be weighed against a set of very real difficulties and costs, and the balancing of these factors places national decisionmakers in something of a dilemma. This is because in an international setting, national governments almost always have multiple policy goals and objectives regarding the performance of the scientific enterprise, and these goals and objectives often are in direct conflict. To cite only the most obvious example, a balance must be struck between the use of research to support domestic firms in the international marketplace and the reliance on cooperative ventures to reduce the high costs of acting in isolation. In short, decisions must be made regarding the international costs and benefits of cooperative versus competitive science projects.[13] Thus, the opportunities and limitations of cooperation almost always are diverse and to some degree a function of a particular definition of national interest, the hierarchy of public policy priorities, and the perception of international comparative advantage. It is possible, however, to make some generalizations about the relative benefits and costs of international scientific cooperation.

The major opportunities and benefits generated by involvement in cooperative scientific endeavors are as follows:

- Making greater resources available, in terms of information, knowledge, and know-how necessary for any scientific activity;
- Making possible a wider range of topics and a broader range of approaches;
- Reducing the financial burden on all participants;
- Speeding up the entire innovation process, from basic research to application;
- Reducing wasteful redundancy; and
- Enhancing good will and communication among the participants.[14]

These benefits fall into three broad categories: the facilitation of the innovation process itself (the first two points), financial advantages (the next three points), and the provision of political opportunities (the final point).

The development and maintenance of good will among partners often is cited as an important political advantage of international cooperation, although this set of benefits is of the lowest priority and the most difficult to calculate. Highly symbolic aspects of megaprojects, such as "space handshakes" between U.S. and Soviet astronauts, have been justified in terms of political benefits of this sort. In addition to the assumption that cooperation will improve transnational understanding and build an appreciation for and tolerance of various cultural and philosophical factors, it is assumed that scientific cooperation can serve as a useful diplomatic tool. In other words, collaboration in scientific activities often is viewed as a useful way to signal approval of the actions of another nation, while the withdrawal of cooperative programs is presumed to send important messages of condemnation.[15] Such was the case with the limited curtailment of American cooperation with the Soviet Union in the wake of the invasion of Afghanistan. These are, however, only signals and symbols. No matter how valuable they are in the political context, such advantages of scientific cooperation are unlikely to provide the basic rationale for engaging in expensive megaprojects, especially in a future likely to be dominated by constrained resources.

Far more significant are the benefits that cooperation provides to the innovative process itself. In the absence of collaboration, the attainment of a critical mass of expertise and funding may be impossible. As a consequence, some projects will not be undertaken and others will be scaled down. For example, the International Geophysical Year would have been an unthinkable undertaking without global cooperation. Also, a variety of participants makes available a broader range of analytical approaches, methodologies, and research techniques than would otherwise be the case. No nation has a monopoly on scientific ingenuity, and the unique resources and talents of many smaller countries are not likely to be utilized in the most effective manner unless cooperative relationships are established.

Most attention in the United States has been devoted to the direct financial benefits of megaprojects. As outlined above, these include the reduction of time, elimination of some duplication of effort, and the spreading of costs over a larger group of actors. In the past, significant benefits have accrued to the United States in each of these categories. For example, the State Department cites task sharing with foreign scientists and laboratories in the lunar sample analysis program as having saved the American taxpayer more than $5 million. Similarly, visits to laboratories and exchanges of technical data in the U.S.-Japan Natural Resources Program were credited with saving an estimated $100,000 to $150,000 by helping American scientists avoid research duplication.[16]

Several important caveats regarding these obvious financial advantages must be noted, however. First, empirical evidence on the payoff from most cooperative activities is sketchy, and often the economic benefits of such projects are not subject to quantification. Second, cost overruns in the management of megaprojects are serious potential liabilities and must be taken into account in any financial analysis. And third, despite the problems encountered with duplication of effort, a certain amount of redundancy in the scientific enterprise clearly is desirable as a crosscheck on the validity of results and findings.

The most significant difficulties and costs associated with international cooperation in science are:

- Inherent difficulties in meshing disparate national bureaucracies;
- Delays in reaching decisions among differing political and legal systems;
- Complications of varying decision processes, priorities, and competencies;
- Costs of international bureaucracy;
- The danger that political inertia, which makes projects hard to start, but even harder to stop, will dominate;
- The possibility of drains on national research budgets because of international commitments;
- The tendency to undertake, internationally, only low-priority projects; and
- The apparent conflict between cooperation and improving a nation's competitive position.[17]

In one way or another, each of these costs of cooperation has to do with the dynamics of national and international organizations, especially bureaucratic ones. Barriers to the implementation of megaprojects include a host of differences among national decision-making procedures, consent mechanisms, and legal frameworks. The degree of centralization of science policymaking, or the comprehensiveness of national scientific planning are only two examples of the factors that help determine how well participants in cooperative ventures are able to mesh their bureaucracies.

An even more troublesome obstacle to cooperation is posed by the very different national science policy priorities that must be integrated into a megaproject. Clearly, nations have very different rationales for and rankings of basic goals and objectives, such as the desire to maximize industrial innovation or the need to maintain the national knowledge pool, and these divergent priorities pose major constraints on cooperation. This is especially the case given the fact that these goals and objectives seem increasingly to be linked to nonscientific foundations. As the OECD has observed:

> (T)he process of policy formulation for science and technology increasingly appears to be based, in some countries at least, upon broader political currents. This is so for a number of reasons but its implication is that the policy process is gradually coming to reflect individual national political values and traditions, rather than something generally characteristic of science and technology.[18]

Thus, the general policy style or political culture of a country may be a more important determinant of science policy than any identifiable importance attached to the scientific enterprise itself or to any special benefit assumed to result from the support of that enterprise. This is not to argue that there isn't considerable consistency between OECD science policy priorities, but that those goals and objectives are far from identical and are shaped by the individual economic, foreign, and social policy concerns of each country. For example, even the current emphasis on stimulating industrial innovation within the developed world masks important national differences in emphasis, and government R&D expenditures in this area actually have been on the decline in a number of countries (Belgium, Sweden, and the United Kingdom, for example).[19]

Given these kinds of complications, it is no surprise to find that bureaucratic inertia is a major concern in megaprojects. In addition to the constraints outlined above, four other factors seem to contribute to delays and higher costs in big science efforts: the requirement to spread financial and manpower resources over a number of scientific problems at the same time; the long time frames within which such projects operate, which generally means that management has trouble specifying the duration of any particular activity; the difficulties involved in maximizing interaction among a range of academic disciplines and other professions; and the rigidity that seems to accompany projects overseeing large groups of experts from diverse national backgrounds.[20]

The problems encountered in organizing cooperation contribute to the higher total cost of international projects, although, as noted above, a significant benefit to each participant is the lower cost. But even the reduced financial burdens of involvement in a collaborative effort may be resisted by domestic research agencies. As in any bureaucratic setting, specialized knowledge and research funds are major sources of political power—sources that may not easily be committed to international ventures if such a policy commitment means a transfer of budgetary or personnel authority to an international organization or a different agency. This tendency to protect bureaucratic territory cannot be overemphasized, and, in a time of intense competition among agencies for funds, the skepticism about international activities naturally is heightened. All this helps to explain why cooperative efforts tend to be assigned relatively low priorities in most OECD science policies and why international collaboration generally is placed at a severe disadvantage in the bureaucratic policymaking process.

Finally, while certainly there is no checklist of how to succeed in international scientific cooperation, it is useful to specify some of the lessons learned in this arena. A review of the literature has revealed the following important conditions:

- Intergovernmental cooperation must be based upon an awareness of the political context, and the further the program moves toward applied research, the more precise the political implications must be.
- It is important that there should be similarity between partners, both in scientific and technical development, and in economic development.
- Aims of the joint action must be clearly defined at the outset.
- A general preparatory mechanism for contact and discussion is necessary to launch, define, and mount the joint effort.
- A detailed cost-benefit analysis of various potential institutional frameworks should be conducted.
- Direct cooperation between national establishments is preferable to the creation of an international body.
- A balance between equity (returns in relation to investment) and efficiency (entrusting work to those most competent to perform it) must be reached.
- Adequate mechanisms for supervision and responsibility in monitoring and management must be provided.
- The international program should not compete with national programs—it should complement them.
- Red tape must be minimized and the delegation of responsibilities maximized.
- Budgets should extend over a number of years to ensure financial stability.[21]

Essentially, these factors point to the necessity of anticipating the relative costs and benefits of cooperation systematically and comprehensively. Planning appears to be a requisite for success in cooperative projects. Also important is the ability to balance political and scientific variables in a pragmatic way. Of course, an underlying assumption of these conditions is that there is some consensus about what constitutes "success" in an international scientific endeavor. In fact, such agreement has been difficult to achieve. Debate about the most appropriate indicators of project success appears to be endless, with some analysts arguing that the scientific significance of the results produced by the project is the only legitimate guideline, and others pressing for the application of broader standards. Thus, it has been suggested that the degree to which the continuity of scientific activity in a country has been enhanced by a project is the best criterion for determining project success.[22]

About the best that can be said for the current state-of-the-art of project evaluation is that something is known regarding the components that many nations appear to consider as being conducive to international partnership. Thus, scientific projects that succeed as international cooperative ventures are typically related to subjects that transcend national frontiers, are costly, have long-range objectives rather than commercial aims, and correspond to the political objectives of the countries involved.[23] Moving beyond these factors to more systematic analysis requires more explicit evaluative criteria. It is here that the Reagan Administration's division of labor approach ultimately may have its greatest appeal. Because this orientation mandates an efficiency standard and a hard look at the scientific capabilities of other developed societies, success may be easier to define—economic payoff in the area of industrial innovation, for example. But implementing such an approach will not be easy. A number of emerging issues must be faced and resolved if American involvement in megaprojects is to succeed within a division of labor approach.

Emerging Issues

Many U.S. cooperative programs in science suffer from the absence of any coherent strategy. The approach used to date, in which decisions are based as much on the overall foreign policy climate as on any particular scientific considerations, accurately reflects the primacy of politics. But it is also a consequence of the very real problems inherent in long-range planning for science and the dangers of overplanning in an environment that changes as much and as rapidly as science.[24] Because today's international scientific programs increasingly are dominated by the problem of funding,[25] this "shotgun" approach no longer is viable. Changing this pattern of policymaking, however, will require coming to grips with some of the most intractable formulation and implementation issues. A big science future based on an international division of labor will face at least four such issues: choice of substantive areas of cooperation, choice of partners, choice of organizational and managerial mechanisms, and choice of funding arrangements.

Choice of Areas of Cooperation

The most fundamental issue confronting U.S. participation in megaprojects is the difficulty of specifying future opportunities. Science policy frequently is shooting at a moving target, and the ability to identify those international projects that will extend and complement domestic activities is made more complex by the need to take into account not only our own dynamic national interests but also foreign capabilities (facilities, personnel, and other resources) and the changing science policy priorities of other countries.

Getting a reasonable picture of scientific capabilities across national boundaries is relatively easy, and this is where most of the attention to date has been focused. Determining how these capabilities are likely to be utilized in a hierarchy of constantly changing science priorities is not so easy. This is as true of broad shifts in emphasis, such as the lower priority attached to social objectives (health or pollution research) by most OECD states today as compared to the mid-1970s, as it is of more subtle changes in goals, like the higher ranking of regional economic development in the science policies of many industrial societies. Yet the ability to anticipate and monitor such changes in priorities, especially in OECD countries, is crucial for big science efforts. Clearly, should the goals and objectives of these potential partners diverge too radically from our own, cooperation would be made more difficult. But too much convergence in priorities also could be dysfunctional. If industrial innovation and economic growth have become the central concerns in most of the developed world, as appears to be the case, cooperation might take a back seat to pressures for competitiveness. According to Tisdell:

> Several governments and societies see the strategy of increased international competitiveness of domestic industries encouraged by appropriate government S&T (science and technology) policies as a means to solve unemployment, reduce inflation and increase economic growth. Countries such as Japan and Germany appear to have used such policies successfully. They can work but they are not certain to do so. Furthermore, the more countries that indulge in these policies the greater the chance of these policies not being successful in the world as a whole. They are not explicitly beggar-my-neighbor policies but they could become so in an inflexible economic world. Thus new difficulties for this *realpolitik* strategy could arise on a global scale even ignoring the possible adverse long-term effects on the environment, the depletion of resources and the social fabric of society.[26]

To avoid this possibility, more comprehensive and systematic priority assessments in the area of science policy are needed. Not only do we need better information about the social methods by which science priorities are set in various countries, but the maximization of cooperative projects requires better understanding of the ways in which formal goals and objectives are translated into funding allocations in science budgets in other societies.[27]

Even assuming comprehension of the range of national science priorities and that these goals and objectives are, on balance, compatible with our own, there are additional dangers associated with the current thrust of American cooperative science strategy. Because a division of labor approach stresses building upon the strengths of the existing international science system, there is the potential that scarce resources will be concentrated in a few established big science fields, like high-energy particle physics. Given the past appetite of megaprojects for money and expertise, resources may not be available for cooperative ventures in less prestigious fields such as environmental protection or the social implications of science. It can be anticipated that the great value now placed on cooperation that has the highest potential for leading to direct economic benefits or that facilitates industrial innovation will only work to reinforce this tendency.

Choice of Partners

The OECD states provide the most attractive opportunities for American involvement in megaprojects. Since similarity between participants (on scientific, economic, and political dimensions) appears to be a crucial requisite for project success, the other Western industrialized democracies naturally have been viewed as the logical U.S. partners in cooperative science ventures. Because Western Europe, Canada, and Japan have capabilities closest to our own, there is more understanding of the potential targets of opportunity, and there is substantial experience in scientific collaboration within the OECD framework and related global institutions. For some time, many of the most productive U.S. cooperative programs have involved OECD nations. Examples of such ventures would include the 1979 U.S.-Japanese agreement to cooperate on fusion research, and the 1980 French-American oceanography cooperative program.[28] A division of labor approach to future scientific collaboration appears to offer promising payoffs with these countries. There are, however, some important issues raised by focusing America's international science policy on potential interactions with other Western nations.

In the first place, enthusiasm about the benefits to be had from megaprojects may not be as high in other democracies as it is here. There is ample evidence, for example, that public spending on big science has leveled off and even declined in many OECD countries.[29] Even within a cooperative framework, there may be the perception that megaprojects spread national resources too thin and that too many other opportunities are foregone as a consequence of channeling of scarce resources to big science. Moreover, there are doubts throughout the OECD system about the level and stability of the various national commitments to international projects. This is as true of the United States as of any other OECD member state. As a recent study by a committee of the American Congress pointed out, "the United States appears to have international cooperation less on its mind than most of the nations, developed or undeveloped, with which it deals."[30] This point has been amplified by Skolnikoff, who has argued that:

> Successful cooperation also requires reliable partners. The record of the United States in modifying or abrogating agreements makes future agreements harder to reach. Most recently, the proposals to cancel the coal liquefaction development project with Japan and Germany and to withdraw from the International Institute of Applied Systems Analysis have damaged our reputation as reliable partners.[31]

If scientific cooperation is to succeed, particularly in megaprojects, participants must somehow develop more consistent, longer term commitments, despite the very real exigencies of domestic and foreign politics.

Finally, it is not clear how an international division of labor decision framework will affect the ability of less developed societies to participate effectively in megaprojects. It is certain that a number of the newly industrializing states, such as Mexico and Brazil, will play important roles in future global cooperative ventures. But because the resources for research are so concentrated in the developed world, there is a danger that significant Third World capabilities will be overlooked in the effort to maximize the scientific talents of the West. Much better information about the scientific resources and policy priorities of less developed countries is needed before major Third World involvement in a division of labor framework can be anticipated. A comprehensive inventory of the availability of scientific facilities, equipment, materials, and expertise in the underdeveloped world would help to resolve many of these uncertainties.[32] Even with the very substantial obstacles posed by differences in levels and rates of economic and scientific development, with the threat of political instability, and with the pressing needs for more applied research and development in the Third World, opportunities for collaboration exist and are ignored in this country at some cost and risk.

Choice of Organizational and Management Mechanisms

The performance to date of megaprojects and of the U.S. science policy machinery suggests several important issues regarding cooperative organizational arrangements. First, there are a set of issues having to do with the appropriateness of existing U.S. planning and policymaking structures for future collaboration in big science. If megaprojects are to be tailored for specific economic and scientific payoffs, then an efficiency criterion appears to demand a fairly comprehensive and possibly somewhat centralized oversight and review capability at the national level. This tendency is made more dramatic by the consensus in this country's science policy establishment that cooperation is facilitated by the use of a relatively large number of bilateral and multilateral arrangements. The conventional wisdom is that these modes of organization are easier to design to more precisely match national interests than is the use of existing international organizations or the creation of new international bodies.

In such a system, planning and oversight become crucial to minimize fragmentation, duplication of effort, and all the other bureaucratic ills discussed above. Unfortunately, the American national science policy apparatus has received mixed reviews of its performance in this area. While there are clear indicators that the role of science in American foreign policy has grown substantially in the last several decades, there is less evidence that this has resulted in a coherent program in the national interest. Critics of the U.S. Government's leadership and organization in science policy emphasize that while there are important advantages associated with our decentralized system,[33] there is evidence that our approach often leads to poor coordination of initiatives, conflicts in policies and goals, inadequate participation from the science community, and a weak sense of international mission.[34] Each of these shortcomings may prove to be damaging to a division of labor orientation. Organizing complex big science projects according to anything like the conditions for success outlined above (the use of extensive preparatory mechanisms, widespread application of cost-benefit analysis, systematic delegation of management responsibilities and provision of stable, long-term budgets) will be difficult in the current system. All this does not imply the need for massive reforms through the extensive reorganization of existing agencies, nor the creation of new bodies (along the lines, for example, of the proposed Institute for Scientific and Technological Cooperation), but a clearer delineation of the responsibilities for cooperative policy formulation and implementation within the OSTP/Department of State/National Science Foundation framework is needed.

The second set of issues refers to the management of big science projects themselves. Here, the major problem in the past and the most significant barrier to the success of megaprojects in a resource-constrained future appears to be the inability to establish and maintain satisfactory mechanisms to involve nonuniversity elements of the private sector. One of the most attractive aspects of an international division of labor in science policy is the potential for tapping more systematically the capabilities of industrial firms at home and abroad. To date it has been difficult to link corporate resources to collaborative projects in ways that are in the national interest.[35] Especially troublesome is the tension between cooperation and competition in the international marketplace, and the resulting danger of a rise in protectionism among the Western industrial states. Resolving this issue will require coming to grips with the very different scientific priorities of private firms (the emphasis on more applied activities, for example), as well as recognizing the significant disparities in decisionmaking styles and mechanisms among multinational corporations and smaller companies.

Choice of Funding Arrangements

Underlying many of the institutional and managerial problems encountered in megaprojects is the issue of funding. For some time, American cooperative programs have been dominated by the problem of securing stable financing in an era of budgetary conflict. Each of the most common methods of financing U.S. collaborative efforts (direct payment by each side of its own costs, each side paying for all in-country expenses, payment by the country that benefits, etc.) has advantages, but each also poses barriers to cooperation. Most significantly, these methods reduce flexibility, induce relatively short-term outlooks, and expose international programs to budget cuts because of difficulties in specifying benefits. As a consequence, several reforms have been suggested. These include the creation of an interagency fund for international cooperation in science and technology, the establishment of a special fund to promote certain cooperative efforts, and the creation of a separately funded organization for scientific and technological cooperation.[36] Each of these proposals tries to reduce the vulnerability of cooperative projects by making it easier to demonstrate the relative merits and liabilities of such activities and by stressing the strategic significance of collaborative ventures.

Budgetary reform also would contribute to the resolution of many of the organizational and managerial issues outlined above. Any rationalization of the planning process in the national science policy institutions is to some extent a function of improvements in the ability to assess costs and benefits of cooperation, and, as noted, this is difficult to do in the existing financial management system.

Policy Options

International cooperation in big science has moved up the hierarchy of priorities on the national policy agenda, as the benefits and opportunities created by collaboration are contrasted with the economic realities of attempting to pursue unilateral projects. As a representative of the U.S. Department of State has put it:

> Indeed, the advantages appear to be compelling enough to suggest that cooperative approaches should not be regarded as exceptional; rather, their potential and promise should be routinely considered as research plans are formulated.[37]

Yet, the attractiveness of international collaboration has not prompted a rush toward the maximization of the potential benefits of joint scientific ventures. It appears as if we continue to view the promise of cooperative projects as exceptional rather than routine. In this environment, opportunities will be missed until and unless policy uncertainties, such as those outlined above, are addressed. At least three policy options may hold some promise for helping to resolve these uncertainties for future cooperation in big science.

Data Base Defining the International Division of Labor

Before we are fully able to operationalize an international division of labor decision framework we must know what it looks like. A major requisite for future advancements in megaprojects, therefore, appears to be the generation and compilation of information regarding the range of scientific capabilities in place or likely to be developed in the world, and more importantly, the various priorities likely to be attached to these capabilities by the diverse nation states. We simply need much more comprehensive data about scientific institutions, personnel, resources, and needs in the OECD states, Communist countries, and the nations of the Third World. And, as discussed earlier, we urgently require systematic information on the ways various countries are likely to rank these capabilities in the short-, mid-, and long-term future. Only if the United States has available this kind of comprehensive data bank can the international division of labor in big science move beyond rhetoric to an operational decision framework.

Of course, much of this information already exists, but it has not been collected and compiled in such a way as to permit *anticipatory* choices. Our data regarding capabilities and priorities is so limited and fragmented that we have been forced to operate in a reactive, ad hoc manner. We need a master roster of all potential partners, including those who for various reasons are today considered "beyond the pale" (for example, Cuba, North Korea, or Vietnam),[38] that lists estimates of current and projected expenditures on a range of scientific priorities, and identifies overlaps and gaps with our own situation.

It is essential that this data base go beyond a characterization of national governmental capabilities to include what is known about the use of laboratories, research institutes, and other mechanisms for carrying out research overseas. We have learned that the OECD experience in these areas offers some helpful suggestions for our own case,[39] and a more comprehensive understanding of global patterns could expand our options dramatically. Similarly, no attempt to define the international division of labor in science will be complete unless better data is made available on the resources and expertise currently in existence and likely to be mobilized by the private firms operating abroad.

Coordination of U.S. Cooperative Programs

A move toward some greater coordination of U.S. cooperative programs is implied in the need for a data base defining the international division of labor in science. Improved information on potential areas of cooperation and possible partners in megaprojects will be useful only to the degree that there is a more coherent system for building consensus and making choices at the national level. At the same time, it must be recognized that each of the major Federal science policy organizations has a strong sense of its mission and that previous attempts to improve coordination have been of limited success. The National Science Board has recognized the need for far more active Federal coordinating mechanisms. In its "Statement on Science in the International Setting," at its September 1982 meeting, the Board argued that:

> Agencies such as the National Science Foundation, as well as universities and nongovernmental professional scientific organizations, will each have unique and important contributions to make toward the success of cooperative international scientific activities. The National Science Foundation, by virtue of its fundamental and broad-based scientific program, should take the initiative, in cooperation with the Department of State and other agencies as appropriate, to bring together potential international partners to accomplish the necessary planning and implementation for international sharing or collaboration in fundamental science and engineering research.[40]

And the Board had the following to say about putting this recommendation into operation:

> The nature of science requires that its international dimension be considered an organic aspect of the scientific enterprise. This dimension must be actively provided for in all Foundation programs, from education and fellowships to the various disciplinary efforts in the natural sciences, social sciences, and engineering. Planning for new facilities and the setting of priorities for major scientific investigations and programs should be carried out with the full recognition of the priorities of other countries and in an environment which encourages complementarity or planned supplementation, cost sharing, and coherence of the various efforts of cooperating countries. National Science Foundation organization and management procedures should reflect these principles.[41]

Most of our potential partners in big science endeavors already have moved beyond this modest effort to centralize national policy for international science, and at least some reforms along this line appear to be a requisite for this country to be able to take meaningful action when the benefits of cooperation manifest themselves.

Line Item in Each Agency Budget for International Science Activities

Calls for incorporating international cooperative programs into the internal bureaucratic decisionmaking process in an "organic" way will remain just talk until we are more explicit about the funding levels for these activities among all Federal agencies. Because political power ultimately is linked to the budgetary process, establishing international science as a separate line item would have the advantages of defining the fiscal dimensions of our international cooperative commitments, developing a more refined calculus of the savings and benefits to domestic programs of our international activities, and removing international cooperative initiatives from their second-class status and thereby reducing their vulnerability to budget cuts in the future.[42] Science policy cannot help but be improved if we remove the current uncertainty about the funding levels of international cooperative programs as a whole, and the funding commitments of specific agencies.[43] We simply must base our decisions on more coherent understanding of the amounts spent on various collaborative ventures and the rationales underlying these expenditures. Otherwise, attempts to develop systematic preparatory mechanisms, including the more widespread use of cost-benefit analyses, and the expansion of our capabilities to evaluate cooperative projects on a comparative basis will continue to be based as much on faith as on empirical evidence of the success or failure of joint scientific endeavors.

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Trends in Collective Industrial Research

Abstract

Collective actions among commercial firms to promote scientific research are based on a number of objectives and take a variety of forms. These forms include trade associations that sponsor research to strengthen a particular industry, groups of firms that work together within the structure of a Federal agency, and consortia involving several firms within a particular industry and one or more universities. While older types of collective industrial research were motivated almost exclusively by factors internal to an industry, recent collective actions have also been stimulated by concerns about international competitiveness, productivity, and the need for trained manpower. The structural and financial arrangements of the more recently established research consortia also suggest that they are becoming an important component of the national technical effort. Although their total expenditures are small relative to total industrial R&D funding, a substantial portion is earmarked for basic research in universities.

Several issues associated with collective industrial research are considered in this paper:

- Will such activity be a significant replacement for Federal R&D support?
- In addition to research, will these efforts address the projected shortage of technical manpower trained to work in selected fields?
- Will such activity set the direction for national R&D efforts in the fields affected?
- What is the relationship of collective efforts to international competitiveness?
- Can this activity provide a significant increase in university support with regard to research, training, or equipment?
- In cases where universities are directly involved, what are the implications for university/industry institutional ties?
- What are the main concerns related to patents, licensing, royalty income, and antitrust regulations?

Introduction

The rapid growth of U.S. research and development since the 1940s has occurred primarily along two separate, though related, streams. One is that of federally supported programs devoted to broad national objectives, including support of the underlying basic science and engineering structure. The second consists of the sum of those research and development activities conducted by individual corporations, constituting the national industrial research effort. Thus, while Government programs have reflected the R&D needs of society as a whole, almost all of the industrial effort relates to the resources and objectives of individual corporations.

Almost all, but not entirely. In addition to the individual efforts each corporation undertakes to pursue specific interests and goals, there are numerous examples where two or more companies, usually in the same industry, have established a working relationship in support of a technical activity without any formal link to subsequent commercial exploitation. This type of collaboration involving several companies which form an association to engage in a technical research or training effort is commonly referred to as collective industrial research.

Collective actions are based on a number of objectives and have taken a variety of forms. The most obvious category of such a relationship is the trade association, some of which sponsor research in various institutions to strengthen a particular industry. There are examples of groups of companies working together within the sanitizing structure of a Government agency. These include the early stages of the National Advisory Committee on Aeronautics, or NACA, the predecessor of NASA, and industry sponsorship of visiting scientists at the National Bureau of Standards. Another category of cooperation is a mechanism for interaction between a group of companies in a particular industry and one or more universities. The recently established Semiconductor Research Cooperative, a research affiliate of the Semiconductor Industry Association, illustrates this type of cooperation. And there are others.

What then is new? And what aspects of collective industry research are of particular interest and importance today? Conventional wisdom suggests that the structural and financial arrangements of these associations may well imply that they are becoming an important component of our national technical network.

What appears to be happening from a survey of groups is that the focused quality of these programs, their operational characteristics, and the amount of funding to support such activities are, in fact, likely to have a considerable impact on the country's technical base. For example, in 1983, four groups alone (Electric Power Research Institute, Gas Research Institute, Council for Chemical Research, and the Semiconductor Research Cooperative) will devote approximately $400 million to these programs. Although this will constitute only about 1 percent of all industrial R&D funding, a substantial portion will be earmarked for basic research and much will go to universities. This reflects a considerable allocation of industry funds to these areas and suggests implications for new university/industry institutional ties in research and training.

Other considerations that have stimulated recent efforts in collective action by industry are concerns about international competitiveness, productivity, and trained manpower. The contribution of these cooperative programs to strengthening the base of a major industry and, relatedly, the base of a technical area or discipline is thus a factor to evaluate. In brief, these activities may affect the direction and, in part, the nature of technical activities conducted within industry and within the university.

Given the level and purposes of collective industrial research, there are a number of issues for consideration:

- Will such activity be a significant replacement for Federal R&D support?
- In addition to research, will these efforts address the projected shortage of technical manpower trained to work in selected fields?
- Will such activity set the direction for national R&D efforts in the fields affected?
- What is the relationship of collective efforts to international competitiveness?
- Can this activity provide a significant increase in university support with regard to research, training, or equipment?
- In cases where universities are directly involved, what are the implications for university/industry institutional ties?
- What are the main concerns related to patents, licensing, royalty income, and antitrust regulations?

These issues are receiving increased attention as a result of broad national concern for nurturing technical leadership and economic vitality. The purpose of this paper is not to offer a comprehensive treatment of the subject. Rather, it is intended to provide an overview of the scope of activities and to indicate areas requiring more detailed research.

Scope of Collective Industrial Research

This section reviews the characteristics and objectives of several types of collective industry associations and their principal activities. The overview of origins and goals of each industry group reflects industry-specific features such as the competitive structure of the industry, degree of regulation, capital requirements, manpower needs, and relevant antitrust restrictions. However, the underlying objective of all groups is to accelerate the pace of technical change by either conducting research in targeted areas and/or increasing the number of trained people required. Clearly, whether the emphasis rests primarily on research or training, there is a reinforcing effect of one on the other.

Within the past decade, and noticeably within the past few years, there have been new forms of collective industry R&D activities established by industry sectors not previously involved and, in some respects, for new objectives. One important characteristic of these newer structures is the magnitude of effort, far above the typical earlier developments. As mentioned earlier, four of the organized activities—the Electric Power Research Institute, the Gas Research Institute, the Semiconductor Research Cooperative, and the Council for Chemical Research—will spend an aggregate total of over $400 million in 1983.

Thus, in our preliminary survey, we have categorized the collective industry associations within two groups: (a) recent developments—organizations established within the last decade and (b) older institutions—organizations established more than 25 years ago.

Recent Developments

Examples of recently established organizations are the Council for Chemical Research (CCR), the Semiconductor Research Cooperative (SRC), the Electric Power Research Institute (EPRI), and the Gas Research Institute (GRI) (see Table 1).

Several characteristics of the Semiconductor Research Cooperative and the Council for Chemical Research are of particular interest:

(1) Both are very recent developments, stimulated in large part by concerns for inadequate basic research in each field and by a concerted attempt among major companies in each industry to respond effectively to both near-term and projected pressures of international competition in high technology.

(2) Both have related goals addressing the need for trained manpower in each field.

(3) Both represent industries which are nonregulated and are highly competitive.

(4) The arrangements for collective action with the focus on basic research and open membership are designed to avoid complications with antitrust regulations.

(5) The amount of funding for each cooperative is significant. Actions of CCR may result in a one-third increase in industrial support for academic basic research in chemistry and chemical engineering, and SRC may become "the largest single conduit for industrial support of university research."[1]

Collective action within the energy industry reflects a different set of characteristics, in large part influenced by the role of energy in the economy, the adverse impacts of OPEC, and the effects of cutbacks in Federal funding.

The Electric Power Research Institute and the Gas Research Institute thus represent several special features of the energy industry:

(1) The requirements for capital and technical resources for energy research, development, and demonstration are enormous and in many cases present an overwhelming burden for any one organization. These characteristics, common to both the electric and gas industries, are reflected in the large membership of electric and gas utilities in these organizations to pool needed resources, and in a substantial level of R&D funding.

(2) Due to the regulation of rates for gas and electricity use through public utility commissions, the energy industry does not have the same competitive structure as such other industries as semiconductors or chemicals. Activity can thus be focused on the development end of the R&D spectrum without extreme concern for infringements of antitrust regulations.

(3) The pressure to work in development and demonstration is reinforced by two factors: OPEC and Federal funding cutbacks. The pronounced emphasis of both GRI and EPRI on energy generation and efficiency is an apparent response to the decade-long supply vulnerability and pricing policies presented by OPEC. The effects of Federal cutbacks are also evident in the program structure of both organizations. EPRI has increased its support for near-term development and demonstration projects from 50 percent to 70 percent; GRI is revising its research program to accommodate a 22 percent reduction in Federal funds for its coordinated funding activity.

Older Institutions

Several older institutions and trade associations have also engaged in collective industrial research. The magnitude of these efforts, however, in terms of membership and amount of funding are modest in comparison to the newer organizations. They appear to have addressed the specific needs of a particular industry in a specialized area of research and/or training, and the level of effort over time is apparently still satisfactory to the participating members. Table 2 provides an overview of two of these older

Table 1
Recently Established Organizations for the Conduct of Collective Industrial Research

INDUSTRY ASSOCIATION	**COUNCIL FOR CHEMICAL RESEARCH** (a nonprofit organization)	**SEMICONDUCTOR RESEARCH COOPERATIVE** (a nonprofit research affiliate of the Semiconductor Industry Association)
GOAL	To boost industrial financial support for basic research on campus in chemistry and chemical engineering, and to ensure high quality advanced education in the chemical sciences and engineering.	"To maintain U.S. leadership in semiconductors and computers through a 25-50 percent increase in pure research and to add significantly to the supply and quality of degreed professionals."*
YEAR OF ESTABLISHMENT	1979.	1981.
MEMBERSHIP	Over 120 universities and 35 companies representing the major chemical and petrochemical industries (figures as of 4/1/82).	Merchant semiconductor companies and their major and leading users (e.g., computer companies, instrument companies, consumer product companies). SRC is an affiliate of the Semiconductor Industry Association (50 companies).
SOURCES OF FUNDING	Membership dues and voluntary participation in CCR's Chemical Science and Engineering Fund (CSEF) designed to increase industry's support of CCR's university members. Based on a formula reflecting number of domestically employed chemists and chemical engineers at each company.	Membership dues and funds contributed by members through a formula based on total semiconductor sales or value of semiconductors incorporated in products.
LEVEL OF FUNDING	Pledges of additional support to universities as of April 1982 equaled $3.6 million.	Programs to begin in 1982. Funding for 1982-1983 estimated at $10 million and for 1983-1984 at $15 million. Could reach $40-50 million per year by 1986.
FUNDING MECHANISM	Companies participating in CSEF pledge their increase to the CCR but actually distribute the funds directly to the university of their choice. There is also a central fund that receives monies from industry based on a 25 percent commitment of the CSEF pledge. This Central Fund is then distributed to CCR university departments based on a formula reflecting Ph.D. students graduated.	Funds distributed by SRC. To be concentrated in major generic areas and institutions rather than spread out over heterogeneous subjects and universities.
MODE OF OPERATING	CCR serves as a mechanism to promote and facilitate one-to-one interaction between industry and university members. There is no peer review, no proposal process, and details of work are handled solely by partners.	Members of SRC will outline program areas and solicit universities for competence in each area. Universities will submit proposals to be reviewed by a technology staff responsible for technical strategy and planning, initiation of contracts, and evaluation of project results. Work will thus be performed by universities.
RESEARCH EMPHASIS	Basic research in chemistry and chemical engineering.	Areas too basic or too long-term for individual industry R&D programs. Possible specific areas: new techniques for imprinting circuits on silicon wafers, alternative semiconductor materials, and computer-aided circuit design.
TRAINING ASPECTS	Interactions to increase research are designed to enhance training. CCR maintains current demand and supply data on chemists and chemical engineers.	Overall explicit goal to increase quality and supply of professional personnel.
EQUIPMENT	Determined by individual partner relationships.	Designed to upgrade necessary equipment and to share skills of personnel trained to operate equipment. The extent of this commitment is reflected in the proposal for equipment to receive twice as much funds as research. The cost of equipment increases at an exponential rate with a 3-year life cycle, which threatens the ability of a university to remain at the frontier of a field for an extended period of time.
INVOLVEMENT OF A FEDERAL AGENCY	No.	No.
OTHER ACTIVITIES	Improved communication links for both information and exchange of scientific personnel between industrial and university laboratories.	
COMMENTS	CCR has potential of increasing the percentage of industry support for university research from 7 percent to 10 percent.	The open membership of the SRC implies that American subsidiaries of Japanese firms would be eligible to join. Representatives of the SRC, however, have indicated that the SRC may establish a policy for such foreign-owned subsidiaries of requiring reciprocal membership in counterpart organizations in other countries. This could apply to present members of the SRC such as Fairchild Camera and Instrument owned by Schlumberger, and Signetics owned by N.V. Philips of the Netherlands as well as potential members representing Japanese-owned companies.

*Botkin, J., Dimancescu, D., and Stata, Ray. *Global Stakes: The Future of High Technology in America*. Cambridge: Ballinger Publishing Company, 1982, p. 94.

INDUSTRY ASSOCIATION	ELECTRIC POWER RESEARCH INSTITUTE (a nonprofit national research and development program)	GAS RESEARCH INSTITUTE (a nonprofit national research program for natural gas supply and utilization)
GOAL	"To advance capabilities in electric power generation, delivery, and use, with special regard for safety, efficiency, reliability, economy, and environmental considerations." (*Annual Report 1981*, p. 1)	To increase supply options for natural gas, improve efficiency for utilization, enhance service, and continue fundamental research.
YEAR OF ESTABLISHMENT	1972.	1976.
MEMBERSHIP	Voluntary membership consists of over 600 investor-owned, municipal, cooperative, and Federal utilities. Membership represents 70 percent of the electricity supplied by U.S. utilities.	200 companies including interstate pipelines, distribution companies, and publicly owned municipal utilities.
SOURCES OF FUNDING	Membership dues based on each member's annual sale of electricity. Aggregate payments to EPRI in 1981 were just below $260 million.	Gas rate-payer. Support is calculated on gas volumes sold by interstate pipeline members and on interstate sales of member companies.
LEVEL OF FUNDING	$215 million for contract research in 1981; $40 million for in-house work and program management.	$68.5 million devoted to R&D.
FUNDING MECHANISM	EPRI's Research Advisory Committee of utility executives and technical staff guides the program priorities and funding allocations.	GRI itself conducts no research. It establishes research priorities and program goals and then contracts work to universities, energy companies, professional service firms, and a variety of research organizations.
MODE OF OPERATING	Detailed strategic planning process is undertaken each year to review requirements and developments of the utility industry. Some work is conducted in-house but most is conducted through contracts let to utilities, manufacturers, national laboratories, and universities.	GRI is regulated by the Federal Energy Regulatory Commission (FERC) through a formal application proceeding whereby GRI submits a 5-year plan of research and proposed rate surchages each year for approval. FERC thus authorizes both rates and program plans; after this process. State public utility commissions also authorize the rates.
RESEARCH EMPHASIS	Nearly 70 percent of EPRI's funding is devoted to these near-term program areas (initial payoff is anticipated within 10 years), with the balance allocated between mid-term (10-25 years: 27 percent) and long-term projects (over 25 years: 3 percent).	Areas and percent of 1981 R&D budget: a) fundamental research, 5.6 percent; b) enhanced service, 8.6 percent; c) efficient utilization, 39.6 percent; d) supply options, 46.2 percent.
TRAINING ASPECTS	Not an explicit goal of EPRI.	Not an explicit goal of GRI, but funds to universities allow graduate students to pursue advanced degrees while performing gas-related research. 1980: 9 advanced degrees.
EQUIPMENT	Funds specialized equipment needed to perform work.	Funded as needed in contract research.
INVOLVEMENT OF A FEDERAL AGENCY	Congressional stimulation to establish EPRI in 1972. EPRI receives Department of Energy R&D funds.	Federal Energy Regulatory Commission grants approval for rates and program plans.
OTHER ACTIVITIES	Information dissemination, workshops, seminars.	Information dissemination, seminars, workshops.
COMMENTS	Federal cutbacks have resulted in shift in EPRI's program structure to reflect greater emphasis on near commercial scale demonstration projects.	Primary emphasis on efficient utilization and supply options; least emphasis is on basic research. Of total R&D budget, approximately $2 million went to universities with $3.2 million earmarked for 1982. Coordinated funding program which included Federal funds is being reduced to $75 million in 1982 from $96 million in 1981 as a result of cutbacks.

Table 2
Older Institutions for the Conduct of Collective Industrial Research

INDUSTRY ASSOCIATION	INSTITUTE OF PAPER CHEMISTRY (independent, privately supported educational and research institution)	TEXTILE RESEARCH INSTITUTE (independent, educational and research organization)
GOAL	To address specialized needs of the paper industry for professional talent trained in the field of paper chemistry.	To broaden the technology base of the textile industry with an emphasis on principles, mechanisms, and understanding rather than development of specific products and processes.
YEAR OF ESTABLISHMENT	1929.	1930.
MEMBERSHIP	Majority of U.S. producers of pulp, paper, and paperboard.	60 corporate participants in the textile and related industries.
SOURCES OF FUNDING	1) annual fees from member companies; 2) contract research performed by the staff on a nonprofit basis; 3) scholarship and fellowship gifts; and 4) miscellaneous sources.	Participant fees, general unrestricted support and grants, industry-supported research, Government-supported research, and publications.
LEVEL OF FUNDING	Annual budget: approximately $7 million per year.	Budget for 1981: $1.3 million.
FUNDING MECHANISM	Offers fellowships in scientific and technical areas related to paper processing and production.	Allocates funds internally for different program areas.
MODE OF OPERATING	The IPC is affiliated with Lawrence College in Wisconsin, and the Institute is chartered as a graduate school although Lawrence College grants either an M.S. or Ph.D. degree.	Most work conducted in-house with training conducted in collaboration with Princeton University. Has 5 areas of activities: research, education, services for corporate members, a monthly journal—*The Textile Research Journal*, and a technical information center.
RESEARCH EMPHASIS	Research is under way in both fundamental and applied areas of interest to the paper industry, ranging in subjects from forestry to waste treatment.	Basic research of industrial relevance in the physical and engineering sciences of polymer, fiber, and textile systems. There are five principal areas of current research: fiber structure, physical properties of fibers, dyeing and finishing, fiber assembly behavior, and textiles in pollution control.
TRAINING ASPECTS	Major emphasis of IPC. About 90 percent of IPC's graduates are employed in the paper industry with the highest concentration in R&D areas.	TRI has a long-established link with Princeton's Department of Chemical Engineering to orient scientists and engineers to fiber and textile science and technology. The program involves both students and faculty at Princeton, and TRI fellowships are awarded for thesis research on textile-related subjects. In 1981, there were 5 Princeton TRI Research Fellows and 2 undergraduate students. Fellowships accounted for about $90,000 of the $1.3 million budget of operating expenses for TRI.
EQUIPMENT	Funds equipment as needed.	As needed.
INVOLVEMENT OF A FEDERAL AGENCY	No.	TRI has received research grants from the Environmental Protection Agency and the National Science Foundation.
OTHER ACTIVITIES	The IPC provides an information service. Its library is regarded as the world's largest collection of scientific and technical literature related to the pulp and paper industry.	A technical information center, research services for members, and a monthly journal—*The Textile Research Journal*.
COMMENTS	Stimulus for establishment reflects lack of concentration in university curricula on paper chemistry. Currently, approximately 25 students complete the Master's program and 10 to 12 pursue studies toward the Ph.D.	

institutions—the Institute of Paper Chemistry (IPC), whose main focus is on education, and the Textile Research Institute (TRI), whose main focus is on research.

Trade associations have also been active to varying degrees in research. As defined by the American Society of Association Executives, a trade association is a "non-profit organization of business competitors in a single industry, formed to render a number of mutual aid services in expanding that industry's production, sales, and employment."

Trade associations have primarily pursued a span of activities including dissemination of information to members on such issues as Government policies and industrywide position statements, sponsorship of conventions and courses, and lobbying of members of Congress on issues of particular interest to the industry. However, the technical unit of a trade association often compiles and distributes statistical data of interest to the industry and may conduct or sponsor research. Most often the research of a trade association relates to testing and standardization of products and processes. Testing facilities can be shared and some are located on university campuses.

Concentrated technical research, as distinct from activities related to testing and standardization, has not been pursued extensively by trade organizations. The Motor Vehicle Manufacturers Association, the American Petroleum Institute, and the American Gas Association are exceptions. There are several other examples of solid research sponsorship by trade associations, but not of the magnitude evidenced by EPRI or even SRC. Thus, the metals industry supports research through INCRA (International Copper Research Association) and ILZRO (International Lead and Zinc Research Organization). Other industries use collective contributions similarly, largely for support of modest grants to individual university researchers. There are a very few instances where the industry conducts collective research in its own facilities. These include the Portland Cement Association and the Textile Research Institute. Such efforts appear to be far more extensive in Europe.

Alternate Forms of Cooperative Research

Research Associates. Industries conduct research through several other cooperative mechanisms. One is the Industrial Research Associate Program established in 1921 at the National Bureau of Standards (NBS) in which scientists and engineers from industry can come to NBS to work with NBS staff. The Bureau does not develop programs or pursue areas specifically to meet the needs of industry. However, there are often programs ongoing at NBS that relate directly to the interests of industry and thus are of mutual benefit.

Each year approximately 100 research associates from industry participate in the program for an average stay of 1 to 2 years. They are selected by the organizations with which they are affiliated and the selections are reviewed by NBS. The two basic conditions of the program are that industry pays all salary, travel, and related expenses of an associate and that all work done at NBS is in the public domain.

Research associates at the Bureau come from both private industrial firms (e.g., Bell Labs, Control Data, Exxon Research and Engineering, Lockheed) and trade associations (e.g., The Aluminum Association, American Dental Association, Society for the Plastics Industry). The overall research focus of the Bureau is to generate measurement techniques, calibrations, and statistical data and to conduct testing.

Currently, there is an effort to double the size of the programs over the next 5 years, particularly in the areas of materials processing, automation, electronics, and chemical engineering. This can be significant because, as a result of reduced Federal support for NBS, such an expansion will optimize the use of the research facilities and augment NBS staff resources in several key areas.

Mission-Oriented Institutes. As another form of cooperative research, several mission-oriented institutes have been established to pursue some area of key research to a particular industry. The Massachusetts Institute of Technology (MIT)-Industry

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Polymer Processing Program is an example. In contrast to the basic polymer industry, which is research intensive, the polymer processing industry has not engaged in extensive research. This area has also not received research concentration at universities. Thus, the establishment of this program was stimulated by the need to increase research commitments in polymer processing, particularly those areas related to the manufacture of plastic and rubber products.

The program began operation in 1973 with a 5-year seed money grant from the National Science Foundation experimental research and development incentives program. Three member companies joined that year. The program now includes 10 members* and is entirely industry sponsored by membership fees based on a formula of each firm's plastics output.

The level of effort consists of about 25 projects directed by six members of the MIT engineering faculty, operating with an annual budget of approximately $500,000. Six patents have been issued to date as a result of the program, with 12 applications pending. Corporate sponsors participate in the program by guiding research directions and gaining first access to research results. All sponsors have royalty-free, irrevocable, nonexclusive license to use any technology developed under their sponsorship.

Policy Issues

The preceding material serves as an overview to identify an activity that is increasing in size and variety and that has the potential for influencing the rate of technical change in the United States. Within this context, the issues presented in the first section of this paper are examined more closely and some of the related impacts are discussed.

Will such activity be a significant replacement for Federal R&D support?

There are several instances where collective industry groups can play a significant role as the pattern of R&D support changes, but this role is not likely to replace that of Federal funding. In 1981, for example, the Federal Government's share of total university R&D funding was 65 percent, while industry in *all* types of support provided 3.8 percent.[2] Additionally, the fundamental transition from Federal support to private sector support in several key areas is likely to involve a period of adjustment in which the impacts on R&D and on the pace of technical change remain unclear.

For example, EPRI has revised the structure of its research program to accommodate reductions in Federal energy support for development- and demonstration-scale projects. Whereas in the past few years near-term programs have accounted for 50 percent of total expenditures, EPRI is now allocating 70 percent for near-commercial-scale projects. To accommodate this shift, however, many programs are being eliminated (for example, support for all work on electrical systems and energy storage technology R&D) or reduced (for example, fossil energy development, development of solar and wind energy, and research on health and environmental effects). In addition, this comes at a time when electric utilities are facing severe financial constraints. This has resulted in an overall reduction in the scope of EPRI's projects over the next 5 years; accounting for inflation, the R&D program will continue at about the 1980 level of real expenditure.

In contrast, the actions of the Council for Chemical Research seem likely to increase the percent of industry support for research in university chemistry departments from 7 percent to 10 percent.[3] While this represents a one-third increase in the current level of industry support, it will not compensate directly for possible reductions in Federal support. However, what may be particularly important here is the improved relationship between universities and industry, based on one-to-one interaction, which may result in a more productive use of technical resources between the two partners.

Will these efforts address the projected shortage of technical manpower trained to work in selected fields?

It seems apparent that the university/industry relationships of collective industry associa-

*For example, GM, Kodak, Xerox, ITT, Instrumentation Laboratory, and Rogers Corporation.

tions can serve to increase the quality and supply of trained manpower. The Institute of Paper Chemistry is a prime example of a collective effort to meet the needs of a particular industry. The newly formed Council for Chemical Research has, as an explicit goal, an intention and funding mechanism to promote advanced education in the chemical sciences and engineering. The funding of research at universities by the Semiconductor Research Cooperative and particularly the focus on the upgrading of expensive, sophisticated equipment suggests a positive impact on the training of individuals in engineering and computer science. Less pronounced, but still a positive contribution to advanced education, is the Gas Research Institute's funding to universities, which allows students to pursue a graduate degree while performing gas-related research.

These trends, nevertheless, were not intended to represent the major solution to the need for trained manpower in different fields. However, they may well provide an important component to the solution, in combination with such other activities as industry-directed professional technical education and training provided by professional societies.

Will such activity set the direction for national R&D efforts in the fields affected?

Rather than setting the direction for national R&D efforts, the collective actions of industry groups are more likely to support or complement R&D directions established by separate industry sectors and the Federal Government, which, combined, constitute the national effort. A consideration of these activities thus rests in a context of how resources are utilized for the Nation's technical competence and whether or not policies are needed in either the public and/or the private sectors to modify this allocation relative to necessary technical requirements and the overall supply of resources.

The total funding of collective industry groups for different research programs is only about 1 percent of all industry funding for R&D. However, the allocation of the collective funding has significance beyond the strictly financial in at least two important ways: (a) greater concentration of technical resources on those points of the R&D spectrum deemed critical by each industry group, and (b) new institutional relationships, particularly between university and industry partners.

The Council for Chemical Research and the Semiconductor Research Cooperative illustrate both points. The chemical and semiconductor industry groups are particularly concerned with ensuring a strong foundation of basic research as an essential ingredient to keep pace with rapid technological change and the intense pressure of international competition. The focus of these groups has, therefore, been on basic research, and the mechanisms chosen have been new and/or strengthened university/industry interactions.

With the SRC, for example, substantial amounts of money will be selectively channeled to universities to upgrade equipment and to conduct basic research. These two efforts clearly imply a major beneficial impact on the training of new professionals in the field of microelectronics. The projected spending of the SRC thus represents a major attempt to strengthen the industry base. Moreover, by funding universities in targeted areas, research strengths and directions at academic institutions will also be affected, and those effects will require evaluation.

What is the relationship of collective efforts to international competitiveness?

In brief, collective industry actions permit a focusing of financial and technical resources in several areas deemed key by consensus of a particular industry group in the hope of contributing to the innovation rate and productivity of the industry, and hence its competitive posture. In several industries, the strength of international competition is threatening the position of U.S. firms in world markets; thus the capacity to respond to this challenge depends upon the best utilization of all resources. Microelectronics is an obvious example.

The record of growth in this industry has been notably high. Over the last several years, the annual compound growth rate of U.S.

industry revenues has been 25 percent. Moreover, this rate is likely to remain high, from 20 to 25 percent, with worldwide revenues projected to reach $75 billion by 1990. The undiminished prospects of such growth are a keen attraction for international competition, which in turn has placed increased demands on U.S. firms for more capital expenditures and R&D to remain competitive. As an example, capital expenditures by the U.S. semiconductor industry are currently about 16 percent of revenue. On the other hand, capital expenditures by the Japanese semiconductor industry consume about 18 percent of revenue, with R&D expenditures at 13.2 percent of revenue.[4]

Other indicators of competition are also germane. From 1970 to 1980, there was a decline in the number of U.S. semiconductor patents issued annually to U.S. companies. During the same period, such patents issued to Japanese companies doubled. Also in the early 1970s, 78 percent of the papers in the prestigious International Solid State Circuits Conference were by U.S. authors, with 5 percent by Japanese authors. By 1980, the percent of U.S. authors had dropped to 60 percent, while that of the Japanese had risen to 30 percent. In addition, the output of electrical and electronic engineering graduates is also significant. Japan is currently graduating about twice as many engineers as the United States, and the U.S.S.R. is graduating about three times as many as the United States. Moreover, trends in both Japan and the U.S.S.R. indicate that the numbers of these graduates are increasing, while in the United States the numbers appear constant.

All of these indicators of international competition underscore the role of coordinated activities to leverage technical and financial resources. The results of the research and training activities of the SRC obviously remain untested owing to its newness, and thus the actual impact on competitiveness is unclear. Nevertheless, it seems apparent that there is a need for pooling selected resources to address broad common problems; this may free other company resources for improving product lines and pursuing other interests.

Can this activity provide a significant increase in support for research, training, or equipment?

Collective industry programs can indeed provide a significant increase in university support. The MIT-Industry Polymer Processing Program represents the establishment of a major new research concentration at MIT, with industry-sponsored funding devoted to equipment and research on processing and manufacturing of plastic and rubber products. The program involves about 25 projects, and 18 patent applications have been developed since the program was established in 1973. While training is not an explicit goal of the program, the research projects offer an opportunity for undergraduates and graduates interested in this field to pursue intensive work in polymer processing.

The CCR and the SRC activities also reflect increased support for universities in research, training, and equipment. Owing to the operational characteristics and funding levels of the SRC, it is possible that universities receiving SRC funding may become centers of excellence in the areas of their special expertise. In such a case, one impact of industry support may be the setting of directions in university research, thus requiring an examination at a university of appropriability and desirability.

What are the considerations for universities and industries for establishing and/or continuing institutional ties?

Industry Considerations. The specific nature of factors influencing technical change in each given industry will vary from one to another. Thus, each industry has a different set of activities that may be appropriate for collective actions. Additionally, economic pressures, Government interactions, and international conditions play a role. As a result, some of the factors that need to be evaluated to assess both the desirability for, and the detailed mode of, collective action include:

- Type of common research that is needed and appropriate;

- Time and cost of program;
- Common concerns of health, safety, and environment;
- Need for standardization;
- Extent of Government programs in related fields; and
- Capacity of companies to pursue work independently

These factors give rise to questions of optimum research management of finite resources, and of strategic business planning with regard to the areas of opportunity for industrial growth and leadership. Collective action can provide a broader technical base for all participants at lower cost per company. By contrast, individual action can be more flexible and thus encourage multiple approaches, more effective integration with other corporate resources, and competitive advantage for the company supporting its internal R&D program.

These factors can also be used to delineate a set of criteria so that an industry, as well as a particular firm within an industry, can determine:

- Whether the industry should initiate or expand collective research activities;
- What relative priorities and emphases should be given to the possible programs to be undertaken;
- Whether a particular company should join in collective research activities;
- What benefits will accrue to a member company;
- What constraints may exist for a member company; and
- What research mechanisms and which university partners—if any—should be sought.

One important pressure for expanded collective R&D is the combination of the broadening technical base required for advances in an industry and the finite resources of money and people available to individual firms within that industry. One way to express this combination is the increased sensitivity to improving R&D productivity. The need for progress and cost-effectiveness may thus result in assigning to collective efforts (a) programs concerned with costly or broadly based programs of technology development, as evident in some areas of EPRI and GRI interests, or (b) depending on the requirements of different industries, programs focused on basic research, such as the CCR and SRC. The impact on each industry sector, as discussed earlier, can be significant.

A second pressure for collective activities is an increasing concern with the technical "environment" within which a particular industry must operate. Specifically, there is a growing uneasiness throughout the industrial research community, of varying intensity depending on the industry, about the production of adequate numbers of well-trained graduates, about the research facilities of universities, and about the ability of some industries to maintain their international competitiveness. To the extent that these "environmental" factors can be improved, the technical base of an industry sector can be strengthened. This motivation was strongly evident in the initiation of the Council for Chemical Research, and it underlies the plans of the Semiconductor Research Cooperative.

The extent to which similar collective actions can be pursued by other industries is not clear. Nevertheless, the elements present in the ones discussed seem valid for (a) industries that face constraints on their pursuit of technical improvement, such as energy, metals, and mining, and (b) other industries immersed in rapid technical change, such as electronics and chemicals. The actions to date may serve as useful models for the future.

University Considerations. Universities are a major participant with industry in the implementation of several collective industry research programs. Since universities are, in a sense, a principal instrument of society for providing a common reservoir of science and technology, and since they function within a special context of goals, motivations, and constraints, their participation in collective industry research efforts involves a different set of considerations and impacts.

The principal concerns of each university in this regard are whether and how to encourage collective industry actions. In the case of the Council for Chemical Research, university personnel, as active members of the Council, are involved directly in planning and implementing the programs.

The continuing attention of universities to the establishment of mission-oriented research centers may be stimulated by the growth of collective industrial research. There would appear to be some attraction in having a university research facility structured to consider the same basic science and engineering problems related to an industry or a mission that are simultaneously the objectives of a collective industry group. In point of fact, without any formal industry action, each mission-oriented research center at a university that sets up close linkages with industry represents a form of collective industry action.

Similarly, this enlarged industrial activity may offer the option for universities to examine and possibly to modify the curriculum and degree offerings to match the changing technical base of particular industries. If this were pursued cooperatively with a representative of an industry association in a given field, then constructive approaches could be considered more easily than would be the case for a university working alone or with the advice of a single company.

Funding from collective industry groups may serve to stimulate increased support for basic research, for training, and possibly for instrumentation. Not only are increased funds likely to be available, but the collective associations may provide a sound base for longer term planning and for broader interactions with those industries.

However, there is clearly a challenge to universities in this expansion. When larger amounts of funds flow through new or modified channels, there can easily emerge strong biases in research within particular fields. This was precisely the situation resulting from the major growth of Federal Government support of R&D during the 1950s and 1960s. For example, during that period the fields of metallurgy and materials tilted heavily toward materials science, with relatively less attention to those areas of process metallurgy that appear to be needed for productivity improvements today.

Despite these influences, the university system tends in general to be reasonably balanced in research. The newer industrial actions should not have the potential unbalancing impact of earlier Government programs for several reasons.

First, industry support of university research is simply too small, on the order of 4 percent of all university R&D. If collective funding programs could double this, it would still not be the dominant factor (See Table 3). And, collective industry funding leaves intact an important characteristic of the university: consideration of R&D as an end in itself, whether in the conduct of basic science or in the solution of particular problems. Thus, there seems to be no basis for concern as to objectivity or undue influence from industrial funding that is still only on the order of 4 percent. A university system hardy enough to absorb and grow with Federal sponsorship, largely from mission agencies, that reached 70 percent is surely able to remain equally independent with industry support that is only a small fraction of the total.

Second, and more importantly, the strong objective of individual companies to develop direct ties with universities will not be submerged within the collective associations. The structure of the Council for Chemical Research specifically provides for a one-to-one relationship between a company and a university. The collective actions in semiconductors and energy are only modest

Table 3

University R&D Funding (in millions of dollars)

	1953	1970	1979	1981 (est.)
Total University R&D	$255	$2,335	$5,183	$6,300
Funded by Federal Government	$138	$1,647	$3,432	$4,100
Funded by Industry	$ 19	$ 61	$ 194	$ 240
Percentage Federal Government	54%	71%	66%	65%
Percentage Industry	7.5%	2.6%	3.7%	3.8%

Source: National Science Foundation. *National Patterns of Science and Technology Resources, 1981.* NSF-81-311. Washington, DC: U.S. Government Printing Office, 1981.

additions to the separate industry-university relations of IBM, General Electric, and Exxon. Thus, the pluralism of research interests will continue.

Nevertheless, there will be an impact on university research by the simple leverage that well-focused collective actions can produce. For example, support of particular microelectronics centers will propel those centers to the forefront of their special areas of excellence, serving to attract Government funds and other private support more easily. Thus, a major impact may be the setting of a direction of university research.

This imposes a continuing obligation on the university to maintain its own independence of research choices, building upon the support available from industry as well as Government sources. The mechanisms in place for the collective industry groups surveyed suggest that universities are in fact carefully screening projects to ensure their appropriateness for academic goals and purposes, and discussing these issues with their industry colleagues.

What are the main concerns related to patents, licensing, royalty income, and antitrust regulations?

The issues of patents, licensing, royalty income, and antitrust regulations are common to all collective research arrangements and are reflected in the operational characteristics and objectives of each organization. When examining these issues, it is useful to keep in mind that there are two distinct categories of collective arrangements: groups such as EPRI that conduct most research at private facilities, and groups that conduct research in collaboration with universities. The following is a general discussion of some of the major points in each regulatory issue. The specific impacts of these issues on each group and, in particular, the effects of the 1980 Department of Justice Guidelines are not discussed here.

Patents. Patent rights are often a major issue related to the conduct of research. The concern lies between the rights of the inventor and the rights of the host institution—usually an employee/employer relationship. The assignment of patent rights for inventions, innovations, discoveries, and improvements can vary with the circumstances. Within a university context, for example, a researcher who performs patentable work with the use of university facilities or services in the course of regular duties generally assigns patent rights to the university. A notable exception is the policy of the University of Wisconsin, which states that the university "does not claim any interest in employee inventions."[5]

Other arrangements for the assignment of patent rights are involved in cases where research is sponsored by a third party. For example, as a result of the Uniform Patent Act, a university or small business can retain patent rights to inventions made in the course of research under Government sponsorship, with three exceptions:

- Operation of a Government-owned research or production facility;
- Exceptional circumstances determined by the Government agency (stringent documentation is required from the agency and is submitted to the Comptroller General to curb abuse by the agency); or
- When necessary to protect the security of Government intelligence or counter-intelligence activities.

In cases where industry is the third-party sponsor, and particularly where a collective group is the sponsor, arrangements for the title to inventions can vary on a case-by-case basis to accommodate the patent policy of an industry group and the patent policy of a university. In the Council for Chemical Research, for instance, all arrangements are made between individual university/industry partners, rather than by the group as a whole, owing to the Council's "one-to-one interaction" modus operandi. For other collective associations, general policies can be made for the entire group of corporate sponsors; these policies are then negotiated with a university.

Licensing. One particular point to consider is the arrangement for licensing when a university retains patent rights under an agreement with a collective group. Here, an exclusive or nonexclusive license may be negotiated. For example, the industry sponsors of the MIT-Industry Polymer Processing Program have royalty-free, irrevocable, nonexclusive license to use any technology developed under their sponsorship. A recently completed study by the New York University Center for Science and Technology Policy indicates that many industry sponsors participating in cooperative research centers do not require exclusive licenses. Exclusive licenses may be more important "in areas of research where the outcome may be a new drug or agricultural product."[6]

Royalty Income. The division of royalty income is also a consideration related to patents and licensing. Again, arrangements vary with individual circumstances. In cases where a third party is involved, such as in research sponsored by collective industry groups at a university, royalty income divisions are negotiated as part of an overall agreement. These divisions can include a share for the university and the sponsoring group, and they may or may not include a share for the inventor.

Antitrust Regulations. Considerations related to possible conflict with antitrust laws are also present in the research carried out by collective industry groups. "Because joint research may involve or create market dominating technology, may be conducted by competitors or potential competitors, or may involve restrictive agreements concerning the use of the results of the research, antitrust issues can arise."[7] Some of the major antitrust considerations are reflected in the focus and structure of different collective groups.

The major points of reference when reviewing the legality of joint research ventures are the nature of the proposed research, the joint venturers, the industry, and the restraints on the conduct of research imposed during the project. With these four points in mind, the general case for not offending antitrust laws involves: (a) research concentrated at the frontier or basic end of the research spectrum, rather than where it may have substantial market effects; (b) a larger rather than smaller number of actual or potential competitors; (c) a narrow field of joint activity; and (d) limited restraints.

The assessment of legality rests in examining the effect on the competitive relationship of individual firms in the collective group. In this regard, there are three major effects of joint research agreements to consider:

- Reduced existing or reduced potential competition between firms;
- Agreement restrictions that restrain competition; and
- Limitations on participation that may give members of the group unfair advantage in the marketplace.

Evaluation of the effects on competition generally involves application of Section 1 of the Sherman Act and Section 7 of the Clayton Act.

Given these considerations, research competition is a key issue. If the research conducted by a collective group serves to decrease competition, then the innovative edge and productivity gains spurred by competitive advantages may decrease, with adverse effects to the marketplace. On the other hand, if joint efforts make possible research that firms could not conduct individually, then the technical base of the industry can be strengthened and thus provide new competitive opportunities derived from the technical advances. Therefore, maintaining or strengthening competition is a particularly important consideration.

The specific arrangements of each collective group are obviously critical and merit detailed examination. An additional point to consider is the role of a "neutral" party, such as a university, in conducting the research. The participation of a university can serve to reduce the anticompetitive potential of research projects conducted by an industry group, particularly in cases where members of the group belong to the same industry and, as individual firms, are highly competitive. The SRC is an example. Moreover, the traditional interest of the university in disseminating results serves to reinforce the anticompetitive potential. University/industry relationships that are part of or are the basis for collective industry research may thus have significance beyond the purely technical.

Possible Government Actions

The preceding comments on the growth of collective industry research are based upon the impact of these activities on the Nation's technical base. Since there are a number of benefits inherent in these efforts, consideration should be given to possible Government actions that might enhance the use of technical resources in these collective arrangements. However, the justification for any Government action to support collective industry research derives from several observations about the objectives and effects of such initiatives.

First, the identification of areas of basic science or engineering most desirable by an industry sector sets a higher probability that advances in these areas will be converted to economic use. Thus, the research directions set by the private sector should be kept clearly in mind when considering the role of a Government action: Will it provide additional support and therefore strengthen a particular trend or will it complement a direction to ensure a balanced base?

Second, support by collective action of common, noncompetitive R&D programs can permit advances to be made on costly and difficult areas that might not otherwise be attempted by a single company. This is particularly true in capital-intensive process industries, such as mining, and can be a factor in raising productivity within an entire industry.

Third, collective industry action to support broad common research interests in a competitive industry can release individual corporate R&D resources for competitive business interests, thus advancing the technical level of an industry generally and strengthening its overall competitive status.

With these observations in mind, there are several areas for possible Government action to enhance the use of technical resources in these arrangements. A key concern relates to institutional arrangements between industry and universities.

(1) Should the Government provide some form of indirect financial incentives, for example, seed money, matching funds or tax deductions, to encourage the growth of collective industry actions?

In the case of the MIT-Industry Polymer Processing Program, the National Science Foundation provided seed money to stimulate research concentration in an area of special interest to a university and a group of industry sponsors. The program's viability and technical contribution have been demonstrated through the ongoing participation of industrial firms and the program's self-supporting mechanism. A critical ingredient here appears to have been the interest of the parties concerned for addressing a needed area of research. Government funding provided the wherewithal to organize the required resources into a program focused on polymer processing research. Similar Government incentives in other areas might merit examination when the interest, need, and conditions of work are appropriate.

(2) Should Government support for basic research at universities expand the directions strengthened by collective industry programs, or should Federal funding be used to emphasize wholly new directions?

This consideration relates to the observation discussed earlier that the identification of areas of basic science or engineering most desirable by an industry sector sets a higher probability that advances in these areas will be converted to economic use. Decisions for Federal funding of basic research at universities should thus account for (a) the overall separate efforts of industry and academic institutions in a particular area, (b) the cooperative mechanisms focused on an area, and (c) the possible gaps in the technical base that could adversely affect balanced economic growth. A consideration of these points may vary from one technical field to the next. Government actions must therefore reflect the sources of technical change in a given field or industry and the points of leverage that require attention. In some cases this may involve added support for a particular research direction, and in other cases it may involve concentration in a separate area.

(3) Can Government support of selected research facilities at universities serve to encourage similar or related actions by collective industry programs in developing cooperative relations with universities?

It seems apparent that excellence in a university research facility can attract cooperative relations with collective industry groups. Government support that serves to strengthen a particular expertise at a university can result in that university's becoming a "center of excellence" in a given research area. This in turn can make the university a more likely candidate for other sources of support.

Of course, the process can also work when industry is the initial, principal sponsor.

As a research facility builds special expertise, it can in turn become a more likely candidate for Federal support.

Conclusion

Collective industry groups are an important component of the Nation's technical base, with implications for overall economic growth and international competitiveness. As such, collective actions and new or strengthened institutional relationships merit (a) detailed examination of impacts on both relationships and technical trends and (b) consideration of Federal policies that can nurture the process when necessary.

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The Impact of Increases in Defense R&D Expenditures on the U.S. Research System

Abstract

Currently under way is a significant reallocation of Federal budget resources, with the Department of Defense (DOD) budget scheduled to increase 54 percent between fiscal year 1981 and fiscal year 1984, while the overall Federal budget increases only 29 percent. During that same period, the DOD budget for research, development, test, and evaluation will increase by 78 percent, while all other Federal research and development expenditures decrease by 12 percent.

This paper explores the potential impacts of these shifts in Federal R&D spending on those institutions with a primary role in the Nation's basic and applied research activities and in the training of scientists and engineers. The data reviewed in the first part of the paper suggest that the major impacts of the increases in defense R&D budgets will be on industry, and particularly on those sectors of industry already engaged in defense-related work. While the overall impact on the Nation's research universities is not likely to be major, there could be substantial impacts on specific institutions and/or among specific disciplines as shifts in research priorities result in changing allocation of research support.

The paper reviews several more qualitative issues related to DOD research support. It notes the willingness of most major universities to take on more defense-related work, but also notes university concern over recent Government proposals to increase control, in the name of national security, over the dissemination of the results of that research. This concern must be resolved if a satisfactory DOD-university relationship is to be established. A major issue cutting across Government, industry, and universities is the impact of the defense buildup on the Nation's pool of skilled scientific and engineering personnel; there is a possibility that universities, the armed services, and some parts of the private sector may experience difficulty in recruiting and retaining engineers and computer scientists, particularly those with advanced degrees. There is likely to be increased competition between defense and nondefense sectors for technical talent.

The paper concludes that Federal investment in all sectors of R&D, not only those clearly related to defense needs, is essential to maintain and improve the technological base of U.S. national security.

Introduction

Between fiscal year 1981 and fiscal year 1984, Federal funding of Department of Defense (DOD) research, development, test, and evaluation (RDT&E)* activities will increase by some 78 percent: over the same period, Federal funding for nondefense-related research and development will decrease by approximately 12 percent. The increases in defense funds for R&D are part of an overall acceleration in defense spending driven by the desire, in the Congress and the Reagan Administration, to enhance the U.S. security posture now and in the future; overall, the defense budget is targeted for a 54 percent increase between fiscal year 1981 and fiscal year 1984, while the Federal budget overall increases only 29 percent. Table 1 presents overall budget patterns for the fiscal year 1981/fiscal year 1984 period.

Significant reallocations of national resources such as these are likely to have broad societal impacts. This paper explores

*For the purposes of this paper, the abbreviation R&D will be used for both civilian and Department of Defense programs; when referring to DOD, this abbreviation is meant to include test and evaluation activities. However it is not really accurate to compare DOD and other agency budgets at this aggregate level, since other agencies either do not have significant test and evaluation activities and/or do not treat them together with research and development efforts. This reporting artifact therefore causes some distortion in understanding the comparative increases in DOD R&D activities.

Table 1

Overall Budget Patterns, Fiscal Year 1981-Fiscal Year 1984

	FY81 Actual	FY84 Proposed	% Change
Federal Budget[a]	$657.2 billion	$848.5 billion	29.1%
Dept. of Defense Budget[a]	$159.8	$245.3	53.5%
Dept. of Defense RDT&E[b]	$ 16.6	$ 29.6	78.3%
Other R&D[b]	$ 19.0	$ 17.0	-11.8%
Dept. of Defense Basic Research[b]	$0.610	$0.869	42.4%
Other Basic Research[b]	$4.497	$5.570	27.9%

Notes:

[a] Outlays.

[b] New Authority, not including construction of facilities.

Source: Shapley, Willis, Teich, Albert, and Weinberg, Jill. *Research and Development: AAAS Report VII.* Washington, DC: American Association for the Advancement of Science, 1982; pp. 6, 27; and Intersociety Working Group. *R&D in the Fiscal Year 1984 Budget: A Preliminary Analysis.* Washington, DC: American Association for the Advancement of Science, 1983; pp. 13, 15, 22, 33.

one such set of potential impacts. It discusses the possible effects on the research system of recent increases in defense R&D spending. The research system, as conceptualized here, is defined as "the set of institutions, facilities, and most importantly, people, whose activities both increase society's storehouse of knowledge about physical, biological, and social reality and investigate ways in which that knowledge can be used for human purposes."[1] This definition, it should be noted, emphasizes basic and applied research activities, rather than development efforts. Such an emphasis is appropriate for this paper, since substantially more attention is given herein to issues and impacts related to research carried out within the Nation's universities than it is to development activities carried out within industry.

A number of recent reports on the state of the U.S. research system have noted "signs of stress, including resource constraints, demographic trends affecting higher education, escalating instrumentation costs, and pressures for short-term returns on research investments...."[2] This paper attempts to cast some light on the interaction between shifts in Federal R&D funding patterns and the policies that underpin those shifts, on one hand, and emerging problems in the research system, on the other. Will increases in defense research spending ameliorate, or possibly exacerbate, some of the emerging stresses? Will the increased role of the Department of Defense in Federal R&D support create new stresses, new issues? Or are the systemwide impacts of accelerated DOD R&D funding likely to be minimal? The following paper provides some preliminary answers to these questions.

Trends and Developments

Historical Perspective

Before examining current and future impacts in detail, it is worth reflecting briefly on the impacts of Department of Defense support on the *creation and evolution* of the U.S. research system in its current form and, in particular, on the development of the Federal Government's relationship to that system. The point of such a historical review is to provide a basis for examining whether what once was, will be again. Although Vannevar Bush's 1945 vision, in *Science: the Endless Frontier*, centered around the creation of a civilian National Research Foundation to serve as the keystone of a post-World War II Government-science partnership, in reality it was the military services that took the 1945-1950 initiatives to create that partnership. In particular, the Office of Naval Research (ONR), established in 1946, was by 1950 supporting over 40 percent of U.S. basic science and had developed a variety of means of providing this support. Most of those means are still in use today. They include:

- Funds for construction of large facilities operated by a consortium of universities;
- Funds for large single-university laboratories, with the research agenda set by a single laboratory director;
- Acquisition of expensive, specialized equipment;
- Funding for unique institutions such as Woods Hole Oceanographic Institute; and
- Project grants to individual investigators to pursue a particular line of research.[3]

The Office of Naval Research supported research, not development, and its major partner was the U.S. university system. The character of that partnership and others between Government and universities developed during the 1940s has been described by the current president of a major research university: "In an overall sense the American university was mobilized for war by the Federal Government in 1941, and demobilization did not occur until twenty-five years later." As a result, he notes, "the American research university yearns for the 1950s and early 1960s....The fact is that we were spoiled. We took a great deal for granted—affluence, growth, the respect of society, a clear sense of purpose."[4]

Although other channels of Government support for research and development were developed or grew in significance during the 1940s and 1950s—the Atomic Energy Commission (AEC), an enlarged National Institutes of Health (NIH), the National Science Foundation (NSF), and the National Aeronautics and Space Administration (NASA)—the Department of Defense continued as a dominant Federal R&D supporter into the mid-sixties. The national shocks following the Korean invasion, the Soviet intercontinental ballistic missile (ICBM) buildup, and the launch of Sputnik reinforced the national security rationale for Federal funding of R&D and, in the case of Sputnik, triggered an across-the-board concern for U.S. standing in science and technology. In addition to support of university research, during the fifties and sixties Federal funds went to a new type of high-technology firm organized to develop and produce the technology-intensive systems required by DOD and NASA, and the "aerospace" industry became a major performer of federally funded R&D. Existing, more traditional firms created new divisions to perform contract work for the Government. Also, a new kind of institution, called a federally funded research and development center (FFRDC), was developed to carry out specialized research tasks, usually for a single Government sponsor. Table 2 contrasts the role of defense-related R&D outlays over the past decades and in more recent times.

In terms of scientific advances and technological progress, this Government-university-industry partnership in R&D proved a powerful success. For example, a recent analysis of the results of three basic research projects at the Massachusetts Institute of Technology sponsored by ONR in the late 1940s and early 1950s identified a "flood

Table 2

Role of Defense Funding in U.S. Research and Development Support

Year	Federal Share				Non-Federal Share
	Federal Total	Defense Related	Space Related	Civilian Related	
1953	54%	48%	1%	5%	46%
1960	65	52	3	9	35
1965	65	33	21	11	35
1970	57	33	10	14	43
1975	51	27	7	17	49
1980 (*est*)	49	24	8	17	51
1982 (*est*)	47	27	6	14	53

Sources: For 1953-1980, National Science Foundation. *National Patterns of R&D Resources. 195*(: NSF 80-308 Washington, DC: U.S. Government Printing Office, 1981; for 1982, author's estimate.

of knowledge and practical accomplishments," and concluded that, "without such support, these benefits would very likely have been postponed for many years or perhaps not have been attained at all."[5] It is probable that similar results would follow from careful study of other DOD-supported basic research efforts of the 1950s. Since 1960, some 20 Nobel Prize winners have drawn direct support from the Department of Defense.[6] At the level of technological achievement, it was the high-technology industries nurtured by DOD (and then NASA) funds that both U.S. and European observers in the 1960s identified as the secret of U.S. economic power; the U.S. leadership position in such areas as aviation, space, microelectronics, computers, and advanced materials was seen as a counter to the erosion of the country's position in other technologically intensive sectors that did not receive direct Government financial support.

Another product of close DOD-science relationships during the 1950s and 1960s was the involvement of some of the Nation's leading scientists with national security programs, either as DOD-funded investigators or as advisers to the Defense Department or the White House on scientific and technological issues related to defense. This linkage meant that some of the country's best minds were familiar enough with ideas for new weapons systems to provide both support and constructive criticism of such proposals.

Even as the momentum of the partnership of the fifties appeared to be increasing, signs of tension appeared. In his farewell address as President, Dwight Eisenhower warned the country of the potential of undue influence on the part of both the "military-industrial complex" and a "scientific-technical elite." During the mid-1960s, as national priorities shifted toward domestic concerns and as U.S. involvement in Southeast Asia became increasingly unpopular on university campuses and in society at large, the partnership between DOD and the Nation's major universities largely came apart. There was a downturn in DOD R&D investments overall, as the costs of the Vietnam War dominated the defense budget. Between the mid-1960s and the mid-1970s, DOD support of basic research, in constant dollars, was cut in half, and DOD funding of R&D overall, again in constant dollars, declined by one-third (See Table 3). Students and faculty on the campuses of many of the country's leading universities questioned the appropriateness of close DOD-university ties. Finally, the Mansfield Amendment of 1969 prohibited DOD research support unless there was a "direct and apparent relationship" to some established DOD function or mission. Though it is difficult to trace the specific impacts of the Mansfield Amendment on particular DOD research investments, the spirit of the Amendment,* coupled with university disaffection and budget constraints, served as effective limits on DOD involvement in overall research policy during most of the 1970s.

The point of this compressed discussion is to point out the central historical role that the Department of Defense has played in the post-World War II U.S. research system, particularly in the Government-science partnership. Will the current step up in defense-related R&D investments have similar broad impacts? Because of the availability of additional DOD funds, will there be:

- Major shifts in the character of, policies for, or mechanisms for Government investment in research and development?;
- More activity in the frontier areas of fundamental science and engineering inquiry, which will result in major scientific advances in the 1980s and 1990s, from DOD-supported research?; and/or
- A lessening or removal of current problems such as obsolete instruments, too few graduate and undergraduate students in science and engineering, and shortages of funding for worthy research?

Will an increased DOD presence in the research system be a source of new controversy, a cause of the diversion of high-quality scientific and engineering efforts away from promising lines of civilian-oriented research, and/or a major contributor to emerging shortages of or bottlenecks in the supply of scientists and engineers? It should be noted that the recent increases in DOD research support are planned to continue

*Although the amendment was legally binding for only one year, its impact persisted.

Table 3

Trends in Department of Defense R&D, Fiscal Year 1965-Fiscal Year 1984 (in millions)

	Current Dollars		Constant FY 1972 Dollars	
Fiscal Year	Basic Research	Total R&D	Basic Research	Total R&D
1965	$347	$6865	$506	$10016
1966	341	7099	476	9903
1967	362	8136	490	11008
1968	318	7908	411	10209
1969	353	7890	436	9752
1970	323	7491	371	8607
1971	318	7654	342	8228
1972	328	8482	328	8482
1973	304	8541	285	8011
1974	303	8578	265	7505
1975	305	9167	244	7324
1976	328	9770	245	7308
1977	373	11385	257	7356
1978	412	11760	262	7468
1979	474	12751	283	7612
1980	552	14150	305	7825
1981	617	17050	312	8610
1982	695	20044	322	9461
1983	788	24300	323	9800
1984	869	29500	339	11500

Sources: Shapley, Willis, Teich, Albert, and Breslow, Gail. *Research and Development: AAAS Report VI*. Washington, DC: American Association for the Advancement of Science, 1982, p. 99 and author's calculations. Report hereafter cited as AAAS, Report VI. The fiscal year 1984 figures are from President Reagan's budget submission.

in subsequent years, and thus their impact may be growing.

Or, will the current and potentially continuing upswing in the availability of DOD funds for R&D have only a marginal, though not insignificant, impact on the research system overall, although impacts on specific institutions or on specific disciplines may well be substantial? The increases in DOD funds may well have the intended effects on the Nation's security posture, and it is primarily on this basis that those increases should be evaluated (though not in this paper). But their systemwide effects may not be as great as it might be expected, given the large increases in R&D spending. In particular, at the level of basic research and of effects on the Nation's research (as opposed to development) institutions, increases in DOD funding are in fact not all that large. The following sections of this paper contain a preliminary analysis of these systemwide effects.

Patterns of Defense RDT&E Expenditures[7]

Tracing the patterns of DOD expenditures for research and development is at best an imprecise art, particularly if there is an attempt to compare them to overall national patterns of R&D expenditures and performance.* Definitions of various categories of R&D activities are different within DOD than they are for civilian agencies, and DOD statistics include test and evaluation efforts in the same accounting system as research and development activities. Reporting systems

*It should be noted that this analysis examines *only* the Department of Defense research budget. National security-related expenditures by the Department of Energy, NASA, NSF, and other Federal agencies are not included in the analysis. A full examination of the total national security research budget is needed, but is beyond the scope of this paper; the assumption here is that such analysis would not markedly change the conclusions of this paper.

and time lags before reports are available also differ. What follows, therefore, should be interpreted as an impressionistic sketch of the current patterns of DOD spending and of performers of DOD research activities, placed in the overall context of national R&D patterns.

Perhaps the central insight from this sketch should be identified at the outset. During the 1945-1965 period, DOD support was a dominant feature of the Federal R&D budget; DOD funding of universities and industry was essential to the overall national R&D enterprise. The picture is somewhat different today. As Table 2 suggests, defense-related R&D funding in recent years is just over one-quarter of *national* R&D expenditures, compared to 52 percent in 1960. Moreover, this quarter of national R&D expenditures is relatively narrowly concentrated. Over 70 percent goes to industry (including FFRDCs), and the industries that receive major defense contracts tend to specialize in defense and space-related work; they are, with a few exceptions, not the industrial giants of the country or the major U.S. actors in international trade. Of research universities receiving Federal R&D support, only one of the top ten DOD recipients gets more than 50 percent of its funds from DOD, and the average "DOD share" of research support among the top ten is 16 percent (fiscal year 1980 figures). (The reality is that the Department of Defense, even during the period it was the major source of Federal R&D funding overall, never was the primary source either of Government investment in basic research or of Federal funds going to universities for R&D. For example, Table 4 provides a historical perspective on the DOD share of funding for university R&D.)

These data suggest the major impacts of the increases in defense R&D budgets will be on industry, and particularly on those sectors of industry already engaged in defense-related work. While the overall impact on the Nation's research universities is not likely to be major, there could be substantial impacts on specific institutions and/or among specific disciplines as shifts in research priorities result in changing allocation of research support. The following paragraphs provide evidence for this general conclusion and suggest where it must be qualified or refined.

Table 4

Sources of University R&D Funding

Year	Non-Federal Sources	Total Federal	DOD[a]
1955	59%	41%	19%
1960	37	63	21
1965	27	73	18
1970	29	71	10
1975	33	67	5
1980	35	65	6

Note:
[a]If DOD funding to universities were to increase by the mid-1980s to more than 10 percent of total support (and this is the implication of recent increases), its impacts could be substantial.

Source: Author's calculations based on National Science Foundation. *National Patterns of Science and Technology Resources, 1980.* NSF-80-308. Washington, DC: U.S. Government Printing Office, 1981.

From fiscal year 1981 to fiscal year 1984, the DOD R&D budget increased by some 78 percent while all other Federal R&D expenditures decreased about 12 percent. When one examines where these increases have gone, the relative narrowness of potential impact becomes even more evident. Table 5 provides the relevant data. Basic and applied research activities (or their DOD equivalents, roughly DOD budget categories 6.1 and 6.2) increased much less than the DOD average, and systems development efforts in such areas as strategic programs increased at well above the average rate; further, these increases in hardware development programs began with a much larger funding base. For example, increases in strategic programs alone required 44 percent of the *total* DOD R&D budget increase in the past 2 years. While the dollar amounts of budget increases do not have a one-to-one correlation with the potential impacts of those increases, the fact that most increases are going to development, test, and evaluation activities puts some limits on the influence of DOD increases on basic and applied research activities overall.

There have been governmentwide attempts during the last three administrations to provide real growth each year in Federal investment in basic research. The increase

Table 5

Distribution of DOD R&D Budget

Category	FY81 Actual	FY84 Proposed	% of Total	% Increase 1981-1984
Basic Research[a]	$615 million	$850 million	2.9%	38.2%
Exploratory Development[a]	$1985	$2963	9.1%	49.3%
Advanced Technology Development	$593	$1233	4.2%	107.9%
Strategic Programs	$3440	$9160	30.9%	166.3%
Tactical Programs	$6130	$8850	29.9%	44.4%
Intelligence and Communications	$1632	$3576	12.1%	119.1%
Mission Support	$2238	$3260	11.0%	45.7%
Total	$16,634	$29,622		78.1%

Note:
[a]These two categories are what DOD defines as the "technology base." Over the past 3 fiscal years, the technology base budget has increased by 46.6 percent.

Source: American Association for the Advancement of Science. *Fiscal Year 1984 Budget Report*, p. 33.

in overall Federal support for basic research over the past 7 years is 159 percent; the corresponding increase in DOD basic research support is 133 percent. In other words, DOD support of basic research has increased at about the same rate as Federal support overall. The pattern is a bit different in recent years, with DOD support of basic research increasing 42 percent between fiscal year 1981-fiscal year 1984, while basic research support from other Federal agencies increased 28 percent. Still, the dollar amounts involved are not overwhelming; DOD support for basic research over that period increased by only $191 million. Indeed, recent increases in DOD basic research funding may be best understood not as part of the national security buildup under the current Administration, but rather as the continuation of a trend that began in the mid-1970s and was given particular attention under the Carter Administration. For example, in 1976 the Defense Science Board conducted a review of fundamental research in DOD, and in 1978 the Office of Science and Technology Policy issued a report (the "Galt Report") that focused on basic research within DOD and called for a reinvigorated DOD basic research effort. An office to oversee DOD research efforts was established under the Undersecretary of Defense for Research and Engineering in 1978, and there was substantial real growth in DOD research budgets in the late 1970s, growth that has continued in recent years.

The Department of Defense spends its R&D money very differently than other Federal agencies do. A recent American Association for the Advancement of Science (AAAS) report noted that DOD "depends on and supports a major segment of the U.S. scientific and technological community through a fairly comfortable pattern of working arrangements, mostly with industry, that has evolved over the years. Other parts of the scientific and technical community, especially in universities, have remained largely outside the military orbit."[8] For example, currently 24 percent of the R&D budgets of nondefense agencies go to universities, while only 3 percent of the DOD R&D budget is spent in academic institutions. The Defense Department puts 74 percent of its R&D budget into industry; nondefense agencies, only 46 percent. The allocations to in-house laboratories are similar: 21 percent for DOD, 30 percent for other agencies.

American businesses receive by far the majority of DOD's extramural research awards. Table 6 lists the top 10 recipients of DOD research contracts. As mentioned earlier, most of these recipients are highly specialized, advanced technology firms that have been created or have been adapted to perform DOD (and NASA) sponsored work; most of them do not have a diversified

Table 6

Major Department of Defense Contractors, Fiscal Year 1981

Company or Institution	DOD Rank	Fortune 500 Rank
Martin Marietta Corp.	1	130
Boeing Co.	2	31
Rockwell International	3	48
Hughes Aircraft	4	213
General Electric Co.	5	11
General Dynamics Corp.	6	76
TRW. Inc.	7	71
United Technologies Corp.	8	20
Boeing Aerospace Co.	9	a
Aerospace Corp.	10	b

Notes:
[a]Not separately ranked.
[b]Nonprofit corporation (FFRDC).

Source: Department of Defense. *500 Contractors Receiving the Largest Dollar Volume of Prime Contract Awards for Research. Development. Test. and Evaluation: Fiscal Year 1981*. p. 2.

Table 7

Universities Receiving DOD Support for Academic Science, Fiscal Year 1980

Institution	Rank as Recipient of DOD Funds	Rank as Recipient of all Federal Funds	DOD Funds as Percent of Total Support
Johns Hopkins[a]	1	1	65%
MIT	2	2	17%
Georgia Institute of Technology	3	47	68%
Stanford University	4	3	17%
Pennsylvania State[b]	5	17	28%
University of Texas	6	32	36%
University of Dayton	7	86	90%
University of Washington	8	4	12%
University of Southern California	9	21	23%
University of California, San Diego	10	5	12%

Notes:
[a]Of Federal support. 71 percent goes to Applied Physics Laboratory. formerly a FFRDC.
[b]Of Federal support. 25 percent goes to Applied Research Laboratory. formerly a FFRDC.

Source: National Science Foundation. *Federal Support to Universities. Colleges. and Selected Non-Profit Institutions: Fiscal Year 1980*. Washington. DC: U.S. Government Printing Office. 1982.

product line, nor do they sell their products in commercial markets. DOD is included in the provisions of a new law requiring all Federal agencies to set aside an increasing portion of their R&D budgets exclusively for small businesses. Other agencies have 4 years to increase the small business share of their R&D spending to 1.25 percent; DOD has 5 years to meet that target figure. What elements of the DOD budget (for example, the test and evaluation categories) will be subject to this set-aside requirement have not yet been determined.

Of the top 500 defense R&D contractors, only 12 are universities; Table 7 lists the 10 universities receiving the most DOD R&D support. Four of these institutions are among the top 10 university recipients of Federal R&D funds overall, but, with the exception of Johns Hopkins University (because the off-campus Applied Physics Laboratory is included in the Johns Hopkins total), in fiscal year 1980 none of these or the other top 6 research universities received more than a fifth of their Federal research support from DOD.

In summary, then, the Department of Defense provides over half of all Federal R&D support proposed for fiscal year 1984, and the DOD R&D budget is increasing much faster than the rest of Federal R&D expenditures. Although the short-term influence of this growth on the Nation's research system may be limited, if the defense buildup continues, and if DOD research and development expenditures continue to grow, the longer term impacts, particularly on high-priority areas of the physical sciences, mathematics, and engineering, could become significant.

Policy Issues

The industrial base for national security programs is not in robust condition, and concentrated attention is being given to improving that situation.[9] But, (a) this is not primarily an issue of science and technology policy, and (b) as already noted, defense industries are highly specialized and exist somewhat in isolation from the mainstream of American industry. Thus, increased budgets for weapons system development are not likely to have widespread impacts on the research system overall. Some problems are likely to emerge from the industrial mobilization to support an enhanced national security posture, particularly with respect to whether sufficient industrial capacity and adequate supplies of skilled scientific and technical personnel will be available for defense requirements without creating significant shortfalls or bottlenecks in the nondefense sector. There are also over 70 DOD research laboratories under service management. Recent studies have identified significant problems within these laboratories, and DOD managers are taking steps to improve their performance. These steps are also unlikely to have significant systemwide impacts, again with the exception that they may make DOD laboratories more successful competitors for the limited supply of technical talent.

With respect to the academic sector, a recent Defense Science Board study noted that

> the universities and DOD need each other. DOD needs the scientists and engineers trained by universities; it needs the faculty pool of scientists and engineers working in the DOD area as originators of new ideas and as expert consultants and advisers. The university research base for defense preparedness is in considerable disrepair and therefore in need of upgrading in faculty, equipment, facilities, and support. The problem is much broader than DOD, but DOD has a specific interest and responsibility and a critical need to see that a solution is found and that the solution is enduring.[10]

In its efforts to develop an "enduring solution" to creating an effective DOD-university partnership, the Department of Defense has taken a number of programmatic initiatives in addition to increasing its investment in academic research. It is in the changing character of the DOD-university relationship that many of the new or emerging issues discussed in this paper can be found. Five such issues are discussed below; following these discussions, issues associated with DOD support of industrial research and issues associated with science and engineering personnel are highlighted.

University-Related Issues

Are Universities Willing to Undertake More DOD-Funded Research? In the current fiscal year, Federal R&D support to universities will total approximately $5.2 billion; of this amount, about $0.9 billion (17 percent) comes from the Department of Defense. Major research universities see themselves in a funding crisis, and thus the possibility of substantially enlarged DOD R&D support is quite attractive to the leadership of the academic community. In recent Congressional testimony, a panel of university presidents suggested that over the next 15 years the Department of Defense "should begin making up" a $4 billion underinvestment in basic research over the past 15 years.[11] One member of the panel told the Congress that "universities today should be and...are willing to do all within their capabilities and limited resources to be involved in meeting national security needs. The great crisis of ideology during Viet Nam has all but evaporated among faculty, students, and staff."[12] Other observers are not convinced that the kind of differences in values and perspectives that drove the academic and national security communities apart in the late 1960s have totally disappeared; recent demonstrations related to a campaign for nuclear freeze may suggest lingering university hostility to DOD programs. A blue-ribbon panel that recently examined national security R&D programs noted "the emotional carry-over of the Vietnam era: students who philosophically reject the concept of strong defense as deterrence combined with faculty who have put aside certain technical fields to pursue investigations less likely to have implications for armament. The institutional suspicion of the military in some schools severely limits their role in the great adventure of keeping the peace."[13] At a minimum, suggests the president of the university that tops the list of recipients of DOD funds, "a nonmobilized community of research universities can and should be more cautious and selective with respect to initiatives from government for new research activities...."[14]

University Concerns over Export Control Requirements. One issue of central importance to restoring a mutually satisfactory DOD-university relationship stems from recent Government proposals to increase control, in the name of national security, over the dissemination of technical information. Since a full discussion of this issue appears in another paper in this compendium, its major elements will simply be highlighted here.[15]

The recent controversy is a reflection of a longstanding tension between the notions of free communication of scientific information and of the need to protect information related to national security interests. There is general agreement on the need for the United States to protect engineering and technological information related to national security; the controversy arises over suggestions that since relatively fundamental scientific discoveries can quickly be incorporated into technology for military systems and since the United States depends for its security on technological superiority, there is a need for controlling access to scientific, as well as technological, information. This is especially the case, argue those concerned with national security, when the Soviet Union and its Warsaw Pact allies are undertaking systematic efforts to acquire U.S. scientific and technological information.

The scientific community has been resistant to attempts to control the flow of basic scientific information, arguing that open dissemination of results and subsequent review and criticism of new findings are essential elements of the scientific process and that any barriers to such flow will impose much greater costs, in terms of slowing scientific discovery and perverting the practice of science, than the potential national security benefits. As Government concerns over the leakage of technical information have increased, the scientific and research university communities have been outspoken in their resistance to additional controls over the activities of the basic research community.

During 1981 and 1982, Administration officials expressed concern that bilateral U.S.-U.S.S.R. agreements for scientific exchanges were one-sided, with the Soviets gaining access in areas where they are weak; that scholarly exchanges were being misused by the Soviets, who were sending senior technical people, some from closed military institutes, to the United States; that much defense-related information was being inadvertently disseminated at professional conferences and scientific symposia attended by scientists from the Communist countries; and that open publication of scientific findings in certain fields was transferring sensitive information to U.S. enemies. The concern came to public attention in January 1982, when the Deputy Director of the CIA addressed a scientific meeting and warned of a "hemorrhage" of U.S. technology to the Soviet Union and of a "tidal wave" of public reaction if the scientific and technological communities did not develop voluntary means for ensuring that sensitive information was not accidentally made available to U.S. enemies.

These recent pressures for increased cotrol over technical information have been met by strong reactions from spokesmen for the scientific community, who argue that any moves toward restricting the activities of basic researchers are not justified and may be both unwise and unconstitutional.

There has been continuing discussion of the "science vs. secrecy" issue in the past year, and a number of groups, such as the Committee on Science, Engineering, and Public Policy of the National Academy of Sciences and the Committee on Scientific Freedom and Responsibility of the American Association for the Advancement of Science, have launched studies aimed at finding a common ground for agreement between the national security and scientific communities. This is a major agenda item for the DOD-University Forum, discussed below. Although there is little doubt that the Department of Defense can impose whatever conditions it chooses over research it funds directly (just as researchers can reserve the right not to accept DOD funds with unacceptable conditions attached), the broader concerns of the research community over a general restriction of scientific communication on national security grounds must be allayed if the major research institutions of the United States are to be willing to engage themselves actively in an accelerated DOD research effort.

Character of DOD Support to Universities. As discussed previously, the increases in DOD funds going to universities, when adjusted for inflation and for the funds set aside for DOD's "instrumentation initiative" (see below), are less than 20 percent of overall Federal funding for university research. Still, DOD university funding is almost equivalent in dollar amount to that of the National Science Foundation and thus far from inconsequential. In addition, over the next few years the "DOD share" of university research support may continue to grow faster than other elements of the basic research budget.

If a particular institution were to receive significant new amounts of DOD funds for research, instrumentation, and student support, the concentration of such funding could substantially alter the character of that institution's research and graduate teaching efforts. Furthermore, DOD support is likely to be concentrated in a few disciplines and fields of particular relevance to national security applications, and this could have major impacts within the basic research enterprise in terms of status, ability to attract the best students, and indeed the pace of scientific progress overall.

In the immediate post-World War II period, DOD funds, particularly those channeled through the Office of Naval Research, were in effect general Government support of, especially, basic research. Such has not been the case for the past two decades, although ONR is still seen as the least restrictive of any Government agency supporting research. Even though the requirement of the Mansfield Amendment that all DOD-funded research have a "direct and apparent relationship" to a military function has been softened to require only a "potential relationship," DOD R&D investments, even those in the 6.1 "research" category, are best understood as *targeted* long-range research support in areas of perceived national security importance, with priority research areas selected by DOD. This has been the case for some time; for example, a 1974 study of DOD-supported projects at Stanford University concluded that "the military had developed a rational, well-administered program to define research priorities in terms of current and projected military needs and to *purchase* (emphasis added) R&D from universities based on those needs. Thus, while the scientific purpose as reflected in each individual project proceeded objectively, funding availability biased scientists' choices on which projects to pursue." To the authors of this study, such external criteria for project selection were problematic; they raised "serious questions about the university's efforts to fulfill its role of protecting the processes by which people search for scientific truth. For nonscientific standards set outside the scientific community to have a heavy influence on the choice of which projects are undertaken may be proper and desirable for industry or Government; but... it is not compatible with the universities' role as agency to protect the scientific process."[16]

This is a rather idealistic view of the scientific enterprise. By accepting external funds for research support, universities at least tacitly also accept some set of externally derived research priorities. Perhaps more realistic is the question of whether an increasing trend toward harnessing research priorities to national security requirements is in the national interest. Certainly DOD research needs are likely to differ somewhat from those defined in the civil sector, and thus there could be shifts in the existing pattern of basic research activities as DOD funds are injected into the system and other sources of funding have decreased budgets. This kind of reallocation of basic research priorities appears to be well under way. Not only research priority decisions but also decisions on which specific projects to fund are, in general, made by DOD technical staff; peer review is rarely used by the Department of Defense.

As part of its accelerated R&D effort, DOD has identified its highest priority technologies as:

- Very high speed integrated circuits,
- High-energy lasers,
- Manufacturing technology,

- Precision-guided munitions; and
- Rapid solidification alloys.

DOD is pursuing a research investment strategy that will support rapid progress in these and other critical technological areas with "order of magnitude" impacts on future military systems.[17]

Historically, research done under national security auspices and in response to national security requirements has been a major source of scientific breakthroughs that are the bases for significant technological innovations of general economic significance. Most of the high-priority research areas targeted for DOD funding also may have potentially broad civilian applications. However, military systems are becoming increasingly sophisticated and specialized, and there may not be as much transfer from military to civilian applications as has occurred in the past. There will be a need for continued attention on the part of DOD and other research managers to making the results of DOD research accessible to the private commercial sector and other Government users, consistent with security requirements.

Also, as particular research priorities dominate DOD investments at even the basic research level, areas of research currently being supported by civilian agencies could become candidates for DOD funding, and lines of research not falling into areas of DOD interest may require particular attention from such agencies as NSF if the best science, regardless of external relevance, is to be supported. There will be an increased need for governmentwide coordination of research support at the disciplinary or program office level, as well as more generally, and NSF may well be required to return to somewhat of a "balance wheel" role as a Federal research support agency. Already in place is a mechanism by which DOD, NSF, and the Office of Science and Technology Policy (OSTP) can coordinate research activities in areas of mutual interest, and this type of coordination is necessary to achieve some semblance of coherence in Federal research policy.

As this discussion suggests, the role of DOD in the support of university-based research will increase in importance, but DOD, as an agency with a nonresearch mission, is a poor candidate to reassume leadership as *the* support agency for academic science. The AAAS notes that some people are asking "since national priorities are being tilted toward defense, and since basic science is so important to national defense in the long run, why shouldn't the DOD budget take on a really major share of support of research at universities?" This view is described as a "pipe dream," one that does not recognize "that it is highly unlikely that DOD could get a national defense priority within DOD itself or in Congress for the general support of basic research."[18]

DOD Instrumentation Support. In recent Congressional testimony, the then Deputy Director of NSF reported "an emerging consensus in universities, the Federal Government, and private industry that there is a critical and growing need to replace obsolete and worn-out research apparatus and laboratory facilities in the Nation's research universities. Although its precise dimensions are not known, there is strong, qualitative evidence that the problem is pervasive and large in scope. A rough, but reasonable, estimate of the lower level of the deficit is $1.0 billion. Upper boundaries of the problem have been placed in the $3.0-$4.0 billion range."[19] Among a number of Federal agencies addressing this problem, the Department of Defense stands out by proposing a 5-year, $150 million initiative to fund university instrument purchases in areas related to DOD scientific programs.

The first grants under DOD's new instrumentation program have recently been announced. The concept is that each service will have $10 million per year, in addition to its research support budget, to allow universities to purchase scientific instruments needed to conduct new, or to improve existing, research efforts in areas of DOD interest.[20]

Both the Defense Science Board and university administrators had called for a DOD instrumentation program equal to 25 percent of DOD's basic research budget, or at least that portion of the budget going to universities. By generous calculation, the proposed initiative is some 4 percent of the DOD basic research budget, and over 5 years would add up to only 15 percent of the minimum estimate of the current need. Still, it is the most identifiable Federal response to a widely perceived problem in the research system, and it could make a meaningful contribution to ameliorating that problem. The DOD instrumentation initiative may provide an example for other Federal agencies to emulate; recent Congressional testimony suggested that DOD should "take the leadership role in establishing programs for the support of facilities and instrumentation."[21]

University-Industry Relationships for Defense R&D. The Department of Defense is attempting to encourage closer ties between defense contractors and research universities. Each defense contractor conducts an Independent Research and Development (IR&D) effort, with about one-third of the costs of this effort being provided by DOD. The purpose of IR&D is to allow defense contractors to develop their own ideas in areas of potential value to national security objectives, as distinct from the R&D they carry out to meet DOD contract requirements. Currently, essentially all of this IR&D effort is conducted in-house by defense contractors, but the Defense Science Board recently recommended that "industry be encouraged to support work at universities through the IR&D route."[22] Such a proposal is currently under discussion within DOD, and various ways of providing incentives to convince industry to channel some portion of its current IR&D funds (DOD provides close to $1 billion/year in IR&D reimbursement to its contractors) or, more likely, to transfer newly provided funds to university researchers. The financial and policy implications of such an initiative could be significant in coming years, as part of the emerging pattern of industry-university connections centers around defense-related R&D.

Issues Related to DOD Support of Industrial R&D

Earlier, it was suggested that defense industries were highly specialized institutions and that their R&D activities may have little connection with nondefense progress in science and technology. In one sense, this was not an accurate characterization; in the past 10-15 years, according to one recent DOD report

> the character of the defense industry has changed significantly. The large prime contractors and major subcontractors are no longer stand-alone organizations devoted primarily to defense business. The companies have become elements of large multi-market organizations and must compete internally for the limited capital that is available....There are strong indications that the return on investment in the defense sector has deteriorated... and that investment is going to the nondefense sector because of higher yields and lower risk. The situation is exacerbated by the instability in the defense market, as evidenced by changing program requirements. As a result, the defense industry is under-capitalized.[23]

Whether or not this is an accurate picture of the present situation, the current defense buildup, if sustained, is likely to make the defense business an attractive proposition to corporate managers. The results of a reemphasis on defense industries, from an overall national perspective, require more extensive examination than is possible within the scope of this paper. A prominent economist has suggested that one pressing issue is

> how the U.S. can maintain the industrial strength to compete with other countries in civilian production and sales. The basic problem here is not so much one of obtaining critical raw materials and equipment, although there may be shortages of both, but is one of skilled workers—craftsmen, engineers, and scientists. Such people will tend to be attracted to military production. Defense contractors will entice workers away from civilian firms by paying higher salaries as they build up their work forces on a crash basis. But even if the salaries were identical there would be a tendency for the most highly qualified people to move into defense. For most engineers, such work is simply more exciting.[24]

Close observers of the defense industry are slightly more optimistic about the capacity of U.S. industry to perform additional defense-related work without dislocations in the civilian economy. For example, the *Defense*

Economics Research Report concludes that "the large growth rates demanded of the defense-supplying sectors relative to their recent levels of growth, the fact that these large growth rates must be achieved across numerous industrial sectors, and the fact that they must be sustained for a lengthy period all combine to provide a quantitative basis for the concerns regarding potential bottlenecks, lengthening leadtimes, and price pressures." The report recognizes that "the problem may be a real one of non-trivial significance," but suggests that "effective management, investment, and worker training could lead to the avoidance of many of these problems."[25]

The major issue relevant to this paper emerging from this analysis is the likely demands from the defense industry on the Nation's pool of skilled scientific and engineering personnel. This problem is discussed in more detail below.

Another issue related to increased DOD support of industrial research is whether the results of that research will find their way into the nondefense sector, so that they can be considered in terms of their potential economic or social benefits. Historically, this transfer process has been a major source of civilian technological innovation, at least according to most analysts. As defense systems become more specialized and distinct from nondefense analogs, DOD research investments may be more difficult to turn into results of broader general benefit to the economy. On the other hand, as has been the case in the past, new and currently unanticipated opportunities for civilian applications with major economic payoffs could result from lines of research that DOD intends to support. Ensuring that the country gets maximum payoff from investments of public funds in R&D support, by DOD as well by nondefense agencies, will require continued Government sensitivity to opportunities for the flow of defense technology into the commercial sector. Heightened concern about the need to control access to sensitive technical information is another element that could impede the process of technology transfer from defense to nondefense applications.

Issues Related to Scientific and Engineering Personnel

An issue on which the interests of universities, Government laboratories, and industry converge is the demand for, and supply of, skilled scientific and technical personnel. Currently there are some 1,600 vacant faculty positions in U.S. engineering schools, and the Department of Defense currently estimates it has 5,000 unfilled civilian and military openings in science and engineering. The Government and the universities, each with their own salary constraints, are competing with healthy and growing defense and civilian industries for a limited supply of scientific and, particularly, engineering professionals. The Defense Science Board reported recently that "DOD and the country face a crisis in the availability of technical personnel." The Board also noted that "over the long run the universities and DOD will have to respond to market pressures in upgrading their science and engineering staff."[26] However, as one recent analysis reported,

> If present undergraduate enrollment trends persist, there should continue to be enough new graduates in most broad fields of science and technology to satisfy anticipated demands through the decade. However, spot shortages do exist in certain subspecialties, and others may develop. The greatest problems at present appear to relate to engineers and computer scientists. University faculties, the armed services, and, in some critical fields, private industry are likely to continue to experience difficulties in recruiting and retaining qualified engineers and computer scientists, particularly persons with advanced degrees.[27]

The DOD research buildup includes increased support for undergraduate and graduate education in science and engineering. In 1981, while DOD employed almost 230,000 scientists and engineers, only some 21,050 students were receiving DOD support of some type, and only 50 graduate students were recipients of DOD fellowships.[28] In the main, the services are increasing their support of undergraduate education through their ROTC programs. The Navy requires that 80 percent of the recipients of ROTC scholarships major in science and engineering: the Air Force, 70 percent. The Army does not have a similar policy, although it is under some pressure to do so. The services are also attempting to increase the size of their ROTC programs.

Beginning in fiscal year 1983, DOD support of graduate education is being substantially increased. All three services plan fellowship programs with awards in most cases substantially larger than comparable fellowships from nondefense agencies. The fellowship stipend will be $12,000, with the host institution receiving an additional $8,000; the total number of students to be supported is approximately 100. DOD fellowship programs are planned to increase in subsequent fiscal years, but clearly they will support only a small fraction of the graduate students needed to meet DOD requirements for advanced training in science and engineering. University officials have suggested that DOD support up to 1,000 new graduate students each year. but this seems unlikely in the current economic climate.[29] Of course, other graduate students are supported as research assistants on DOD-funded projects: the current estimate is that some 4,000 students receive such support. One issue here is whether the comparative financial attractiveness of DOD fellowships will attract a disproportionate share of the best undergraduate science and engineering students into DOD-related work. Proposals have been made that DOD fellowship programs include the provision that recipients work one year in DOD laboratories for every year of graduate support they receive, though this is not currently a requirement.

One attempt to steer promising younger students toward defense-related research deserves mention. In July 1981, the Department of Defense established a science and engineering apprenticeship program for high school students to stimulate broader interest among students in science and engineering careers and to establish individual working relationships among students and active researchers. The program is executed by individual DOD laboratories and by the scientific officers responsible for the Army, Navy, and Air Force research programs. The minimum age limit for the apprenticeship program was relaxed by the Office of Personnel Management to allow employment of high school freshman and sophomores aged 14 and 15 years. DOD sponsors of apprentices are particularly encouraged to refer promising graduates of the apprenticeship program to other DOD laboratories in the communities where the student intends to attend college. If successful, these programs and referrals will direct student scientists/engineers toward defense-related research and issues and, perhaps, toward ultimate employment by the Department of Defense or its contractors.

The role of DOD in support of graduate education in the United States is likely to remain relatively limited; however, a recent review of defense R&D concluded that "an investment in 20 thousand more Ph.D.s in science and engineering today—costing society perhaps $2 billion—will be worth, in terms of military deterrence and national security, many times the $2 billion cost of a future division or air wing."[30] It seem unlikely that this kind of argument will carry much weight as the country considers how best to enhance its defense posture in coming years.

Conclusion

The major findings of this analysis have been identified earlier. but are worth restating. The tentative nature of these findings should be emphasized: as the AAAS R&D analysis remarks, "in many respects it is still too early to see the real impacts of changing funding patterns...the real impacts...will not be felt at colleges and universities until some time in 1983. and perhaps later."[31]

All of those who have considered emerging issues in the U.S. research system of the 1980s have identified the supply of well-trained engineers. and particularly of engineers with graduate degrees and/or who are U.S. citizens. as a major concern.[32] This paper reinforces that concern, and suggests that a major impact of increases in DOD R&D budgets overall is related to availability of and competition for engineering talent. DOD funding will go primarily to the aerospace industry for development of new military systems, and this may well create, in a competitive personnel market with limited supply, a bias among individuals toward DOD work, since it will offer both exciting work and high salaries. Universities and perhaps even civilian industry may find it increasingly difficult to attract the best people, given this defense-industry competition.

To meet the growing demand for scientists and engineers, U.S. colleges and universities will have to attract more well-qualified students to technical concentrations and increase the flow into the economy of graduates at the bachelor's and, particularly, the postbachelor's level. There are likely to be insufficient numbers of qualified faculty available, especially in engineering schools, unless the current state of affairs with respect to faculty salaries and working conditions is significantly improved. The Department of Defense has recognized this situation and is attempting to find ways to help ameliorate it.

Attempts to reestablish a mutually satisfactory DOD-university relationship will most likely continue to create policy controversy. More generally, university leaders are exhibiting some ambivalence and skepticism about the changing character of Government-science relationships in general; some observers think that "recent cutbacks in nondefense R&D are unprecedented and have significantly eroded the faith of many members of the scientific community in the underlying stability" of Government policy for academic science.[33] The prospect of increases in research, instrumentation, facility, and fellowship funds from DOD is very attractive to universities that perceive themselves in difficult financial condition. Yet, there are concerns about the conditions of DOD support, such as export control requirements, and about excessive dependence on a source of funds that has had a "stop and go" record of university support over the past two decades. A DOD-University Forum has been created as a vehicle for discussion of such issues as science and engineering education, export control requirements, and foreign language and area studies efforts; DOD is attempting to involve itself more actively in science policy discussions at a number of levels.

This paper has concentrated on the effects of increased DOD support on the U.S. research system overall. But the relationship is a two-way path; there are important questions related to the contribution of the Nation's research system to its overall national security. A recent review of how to assure this contribution concluded that "it is not possible to separate purely military activities in science and engineering development from those that have broader economic, exploratory, academic, or social rationales for their pursuit" and stressed "the important relationships that tie our military R&D programs closely into the larger technical problems of our society....Healthy military R&D can flourish only in a healthy overall R&D environment."[34]

Increases in DOD R&D funding, by themselves, will not achieve the desired objective of improving the technological basis of U.S. national security. The effects of those increases must be evaluated in a systemwide context, and national science and technology policy should be adjusted to facilitate the the adaptation of the U.S. research system to changing priorities, requirements, and funding patterns. Only by coordinated policy development can the United States receive the full benefits, in both defense and nondefense sectors, of Federal investment in research and development.

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Training and Utilization of Engineering Technicians and Technologists

Abstract

The training and utilization of the "technical workforce"—engineering technicians and technologists who support engineering activities—has emerged as a serious national policy issue. Three dimensions of the issue are explored in this paper: its relationship to the enhancement of productivity, the mismatch of technical training with jobs, and the growing financial constraints on the institutions that train the technical workforce. Trends and developments of the last decade underscore the need for better supply-demand data on this workforce and on the job skills defined by geographic and industrial service areas. The complementary roles of four institutional actors—educational institutions, industry, Government, and professional associations—are described and linked to the individual process of career choice. Industry's role appears to be pivotal in clarifying training and utilization opportunities for engineering technicians and technologists in the United States. However, new patterns of cooperation and initiatives on the part of all four institutional actors are likely to be essential if the projected national need for associate and baccalaureate degree technologists is to be satisfied.

Introduction

At least since Sputnik I, science and engineering manpower has been a national policy issue. One component of this manpower is the "technical workforce"—engineering technicians and technologists who support engineering activities. Although the importance of this non-Ph.D. and mostly industrially employed workforce has been recognized, a gap in our manpower knowledge exists. This paper seeks to analyze trends and developments in the supply and demand of this workforce during the last decade, discussing the unique but complementary roles of various institutional actors and proposing specific policy options for clarifying, and perhaps creating, training and utilization opportunities for engineering technicians and technologists in the United States.

There are at least three dimensions to technical training as a national policy issue. The first relates to the mismatch of training with jobs (the so-called underemployment question), the second to the growing financial constraints on the institutional producers of the technical workforce, and the third to the enhancement of productivity. This section provides a brief overview of these issues. The next section discusses evidence for the tentative conclusions reached in this overview.

Technicians and technologists enhance national productivity by augmenting the engineering workforce. Technicians can be educated in 2 years rather than 4 years. While a technologist holds a 4-year baccalaureate degree, a technician holds a 2-year associate degree in an engineering or an industrially related (nonhealth, nonbusiness, or nonagriculture) technology.[1] But the definitional distinction associated with technician-technologist training is routinely ignored by industrial employers. For example, technologists are often classified as engineers. To blur the distinction further, associate degree technician graduates can easily continue their education in bachelor degree technology programs.[2] However, it is very difficult for technicians to transfer to engineering curricula and receive credit for their past academic work.[3] Consequently, there are discontinuities created by the educators (or producers) of the technical workforce that are not observed by the consumers of that workforce.

A related problem concerns a possible mismatch between student enrollments in technical courses and personnel demand. Technical educators can often identify areas of manpower shortage and are often in a position to sense the aggregate effects and trends of employers' demands over a rather long term. However, student enrollments rarely reflect these assessments. Most technical educators agree, for example, that there are critical shortages of technicians and technologists in computer software and hardware, digital instrumentation and control, computer-aided drafting, computer-aided manufacturing, energy, and environmental systems. Yet, other educational areas that have a persistently low demand often enroll large numbers of students.

The mismatch of training with jobs means that American industry uses many engineers in positions more appropriate for technicians and technologists. As a result, many engineers are underutilized by being assigned duties for which they have had little training or education. This, in turn, affects morale, productivity, and turnover. A short-term challenge, in a nutshell, is to set engineers free from such tasks. The persistence of these practices on the part of American industry seems to be due to three factors: insufficient knowledge of the capabilities of technical personnel, the inertia of past personnel practices, and the growth (plus inevitable variability) in technology education itself.

The costs for providing such education continue to escalate. The 2- and 4-year institutions that train technicians today must cope with severe constraints on their ability (a) to attract and retain quality faculty, and (b) to purchase new equipment. Technology faculty need to be familiar with the latest industrial techniques; therefore, they need ongoing industrial experience. Individuals with such skills are reluctant to leave industry to go into education full-time where salary levels are low. And many educational institutions do not differentiate in teacher salaries between high-demand and low-demand technical fields.

Faculty for technician education programs have master's degrees, typically in education or engineering, or an equivalent bachelor's degree and licensure. But neither engineering nor education master's degree work advances the knowledge of the teacher in the technology in which she/he must teach. Likewise, the few master's degree programs in technology are teaching programs rather than technology programs.[4]

Because technology education is at least as, if not more, equipment-intensive than is science or engineering education, the widespread introduction of computers has made much existing equipment obsolete and replacement equipment very expensive. Few, if any, educational institutions seem to have enough money to devote to the training of faculty, the development of instructional materials, or the purchase of new equipment. Whereas engineering education leads in the faculty shortage crisis, technology education is most affected by the equipment crisis. If technicians are being trained to become productive practitioners immediately upon graduation, they need to learn how to operate state-of-the-art industrial equipment.

If technology educational institutions are not able to afford modern equipment and training of faculty, an educational system that should lead the Nation's technology is apt to fall behind prevailing practice in industry. Indeed, industry is compelled to institute extensive on-the-job (re)training programs, diverting talented individuals (both the industrial trainer and the company neophyte) from the productive work they could otherwise do. Thus, the financial constraints felt in the training capacity of educational institutions could have far-reaching effects, contributing both to the underemployment and "worker-readiness" problems and, ultimately, to lags in company, industry, and national productivity.

The present tendency to misuse both engineers and technicians could also affect productivity. Inasmuch as engineers in the United States are no longer educated for the shop (now the province of the "craftsman"), the industrial plant, or the laboratory, it is technicians and technologists who must do this work. Yet, at present, far fewer technicians and technologists are graduated than engineers. With the advent of the "high technologies"—which typically involve electronics and computers in their implementation—industry must recognize who is trained to do this work, and then title and utilize these personnel accordingly. The effectiveness with which this is done has implications for the larger issues of productivity and technological competitiveness.

Trends and Developments

Technical Manpower Statistics

Planning educational programs that prepare individuals to enter specific niches in the workforce requires reliable statistical information and projections. To the extent that statistical information and corresponding occupational definitions are lacking, human and economic resources are inefficiently expended and the needs of individuals and employers alike are not met.

Depending upon the sources of the statistics, and there are many, information on specific occupations varies greatly. Traditional professional personnel, such as scientists, engineers, accountants, and architects, and easily identified craft occupations, such as barbers, machinists, and carpenters, tend to be accurately counted. The less understood and inconsistently defined occupations, such as technicians, receive short shrift, usually in the form of gross statistical aggregation or partial coverage. A review of Federal statistical sources (Department of Labor, Department of Commerce, and the National Science Foundation) and commercial and professional research publications (Conference Board's Help Wanted Index, Scientific Manpower Commission, American Association of Engineering Societies [AAES] and National Society of Professional Engineers [NSPE]) yields the conclusion that there is a national dearth of information on engineering technology and that what is available generally lacks the detail necessary for educational and career planning.

Nevertheless, some general trends, by degree level and curriculum category, can be discerned. For example, the Department of Education reports that for the 10-year period between 1970-71 and 1979-80, the number of associate degrees (at least 2 but less than 4 years of postsecondary work) conferred showed the largest numerical increase among all levels of degrees. The largest increases also occurred in science- and engineering-related occupational curriculum categories, with women experiencing greater categorical gains in the percentage earning associate degrees in technological areas. Overall, 2-year institutions conferred an average of six times more associate degrees than 4-year institutions over the decade, the 1979-80 ratio being 350,000 to 60,000. Public institutions conferred 85 percent of these associate degrees.[5]

The most recent, and disaggregated, profile of associate degree conferrals is presented in Table 1. It summarizes occupational curriculum totals divided first by "science- and engineering-related" vs. "nonscience- and nonengineering-related" categories, and then by technological area within each. These areas are shown by sex and curriculum type to illustrate the current supply-side configuration as we entered the 1980s. Note that the "mechanical and engineering technologies" area is second only to "health services and paramedical technologies" in total associate degrees awarded and first in awards based on 1-2 year curricula.

Demand statistics are more difficult to find. Operational definitions of the many types of engineering technologists are still not widely available and hence preclude sufficiently large numbers of employers from incorporating the title "engineering technologist" into their manpower plans. Estimates of the technician workforce—engineering and science technicians are treated as categorically the same—hover around 1 million. A 1980 Bureau of Labor Statistics (BLS) bulletin offers a 1978 employment figure of 600,000,[6] while a more recent Occupational Employment Statistics projection matrix lists the same category of the workforce as totaling 1.25 million in 1980. About 80 percent worked in private industry. And within the manufacturing sector, the principal employers were the electrical equipment, chemical, machinery, and aerospace industries. The Federal Government employed approximately 100,000 technicians in 1981, with the largest number located in the Department of Defense.

According to a joint 1980 National Science Foundation/Department of Education report,[7] the demand for technicians, technologists, engineers, and scientists will remain strong through the 1980s. There will be over 30 percent more new jobs in those fields during the decade. A 1981 Scientific Manpower Commission report[8] pegs the demand at 375,000 new jobs for engineering and science technicians and places the overall growth rate at 38 percent from 1978 to 1990. The employment outlook is uniformly excellent, as summarized in Table 2.

The lack of a specific category for technologists suggests that they are included in unknown proportions in the engineer and technician data. However, by deriving the

Table 1

Associate Degrees and Other Awards Based on Occupational Curriculums, by Length and Type of Curriculum and by Sex of Recipient: United States and Outlying Areas, 1979-80

				Awards based on organized occupational curriculums of—					
	All awards			At least 2 years but less than 4 years			At least 1 year but less than 2 years		
Curriculum	Total	Men	Women	Total	Men	Women	Total	Men	Women
Occupational curriculums, total	353.333	158.647	194.686	278.555	127,191	151.364	74.778	31.456	43.322
I. Science- and engineering-related curriculums	193.532	96.510	97.022	144.703	70.948	73.755	48.829	25.562	23.267
A. Data processing technologies	15.147	7.525	7.622	12.560	6.616	5.944	2.587	909	1.678
B. Health services and paramedical technologies	86.647	10.322	76.325	66.452	8.222	58.230	20.195	2.100	18.095
C. Natural science technologies	19.214	11.536	7.678	14.431	8.743	5.688	4.783	2.793	1.990
D. Mechanical and engineering technologies	72.524	67.127	5.397	51.260	47.367	3.893	21.264	19.760	1.504
II. Nonscience- and nonengineering-related curriculums	159.801	62.137	97.664	133.852	56.243	77.609	25.949	5.894	20.055
A. Business and commerce technologies	124.485	44.512	79.973	102.557	40.591	61.966	21.928	3.921	18.007
B. Public service-related technologies	35.316	17.625	17.691	31.295	15.652	15.643	4.021	1.973	2.048

Source: U.S. Department of Education, National Center for Education Statistics, *Digest of Education Statistics, 1982*, Table 123 (adapted).

projected average annual growth in the technician labor force from Table 2, under Low Trend and High Trend II (conservative economic optimism) assumptions, and comparing the supply of graduates from Accreditation Board for Engineering and Technology (ABET)-accredited programs, an indication of how demand is being met can be inferred. There appears to be a considerable undersupply of technology graduates, but the data include neither Bachelor of Science in Engineering Technology (BSET) nor any industrial technology degree statistics, a total of more than 19,000 additional technology degrees. When these are considered, the AAES-estimated shortfall of 16,000-20,000 disappears.[9] This suggests that there is an ample supply of technology manpower to cope with demand. It also leaves the supply from all nonaccredited schools not included in the AAES estimates to compensate for elasticity, deaths, and retirements of the technicians and technologists who move into jobs that are mistakenly counted in the "engineer" category.

The statistics indicate that any expansion of technology education programs should be very carefully evaluated, not only on the basis of national projections, but on the assessed needs of the geographic service area of the program.[10] Although national data may suggest that a near balance of technician supply-demand exists, needs for more individuals with certain technical specialties in specific geographic areas can also exist to justify new or expanded technical programs. Clearly, a major obstacle to educational planning is the very limited breakout of technical specialties reported in national statistics. This underscores the

Table 2

Labor Force Projections for Engineers and Technicians (1978-1990)

Occupation	Employment (in thousands) 1978	1990 Low Trend	1990 High Trend	1990 High Trend II	1978 Technician/ Engineer Ratios
All Engineers	1.071	1.504	1.624	1.531	—
Aero-Astronautical	57	98	104	100	—
Chemical	53	68	73	70	—
Civil	149	208	218	211	—
Electrical	291	441	479	448	—
Industrial	109	146	159	148	—
Mechanical	199	274	300	279	—
All Engineering & Science Technicians	1.160	1.577	1.700	1.609	1.08
Drafters	293	412	446	419	—
Electrical & Electronics	319	464	512	478	1.10
Industrial	31	40	44	41	0.28
Mechanical	45	61	67	62	0.23
Surveyors	54	73	78	76	0.36

Source: Scientific Manpower Commission. October 1981.

need to consider an educational institution's geographic service area in the planning of technician training programs.

Institutional Actors and Roles

Several institutional actors have already been identified as participants in the process of educating and employing the technical workforce. Foremost, these include educational institutions and industrial employers. Underlying their effectiveness, however, are the linkages and barriers that affect career choice, attracting and repelling individuals from occupational niches they are more or less trained to fill. The matching of trained talents to jobs goes well beyond national supply-demand statistics to changing well-entrenched perceptions and practices.

The Industrial Connection. In his book on occupational education and industry,[11] the late Samuel M. Burt cited "confusion on the part of industry concerning how to work effectively with the schools" and "disillusionment on the part of industry...to establish effective relationships with educators" as major obstacles to responsive occupational education programs. In technology education, those obstacles have become formidable. One language that is understood by both industry representatives and technical educators is a job task statement inventory for each technical field. Despite the investment of considerable Federal funds in computerized job task banks intended to serve occupational educators, no engineering technician job task statements existed for any field as late as 1976. Since such statements are critical to implementing a job-related, individualized, computer-generated and computer-scored certification examination system, the Institute for the Certification of Engineering Technicians (ICET) undertook in 1976 to create job task inventories for the many fields of engineering technology. These job task inventories proved to be an effective language for communicating with many different employers, examination committees, Government officials, educators, and engineers. They also appear effective as career guidance tools.

Similarly, job descriptions reflect employers' decisions in structuring specific positions. These positions often differ from employer to employer because of firm size, type of business, capabilities of employees, and other factors. Therefore, management decisions are made to accomplish a mission utilizing particular manpower configurations. As a result, employers tend to assign different duties to persons with the same technical background.

These differences are especially noticeable in descriptions used by Government agencies and private firms as opposed to military organizations. The mismatch of educational requirements for job assignments is due largely to time constraints in the military training program and the narrow job tasks associated with most military technician assignments. But the mismatch can be identified and managed by utilizing a matrix of courses by job tasks. Some of the job tasks and courses, of necessity, need to be broken down to fit the military system, but a considerable portion of the requirements turns out to be common to the military and civilian sector, thereby creating new opportunities for military-civilian educational cooperation.

Industry also responds to its training needs by developing materials on specialized topics. Aside from those of a proprietary nature, these materials can be made available to technology schools. Contemporary technical educators, pressed by the rapid expansion of technological knowledge, must realize that an entire field of technology cannot be imparted to students in 2 years. In any technological field, the rich variations in job tasks overshadow the meager sampling found in 2-year technician curricula. Civil engineering technology, for example, includes highway design, construction, materials testing, surveying, traffic engineering, buildings, structures, water systems, rail systems. wastewater systems, environmental protection, safety, dams, waterways, and ports. Beyond an underlying core, the educator is confronted with an array of alternatives from which she/he must select a major part of the instructional program. At the point of specialization, employer input of specific job tasks can assist the educator in making critical choices of curriculum and course content for the school's geographic service area. Once the choices are made for required and optional content, industry-produced training materials can contribute to the quality and relevance of the program.

Even using a job task inventory, however, the technical educator should obtain employer input throughout the service area. With ever-shrinking school resources, educators have neither the time nor funds to design and implement cost-effective programs by themselves. The alternative is misaligned technical education programs, unrecognized employer potential, and the lost opportunity to bring employers and practicing engineers, technologists, and technicians into curriculum design and the teaching process per se.

Career Choice. Where does the technical workforce originate? Early educational experiences and aspirations initiate a process that results in "career choice." This decision is a subjective response to the cumulative social images and pressures that family, friends, teachers, and others bring to bear. These "others" are often professional organizations. For example, guidance materials for engineering and technology are produced by the National Executive Committee on Guidance (NECG) on behalf of the engineering profession. NECG includes representatives of NSPE, ABET, and the American Society for Engineering Education (ASEE). Millions of booklets and brochures have been distributed to secondary schools throughout the United States. Exhibits are displayed at the annual conferences of the National Science Teachers Association and the American Personnel and Guidance Association. Films and slide shows are made available, and kits for presentations by engineers are sold for a nominal sum. In addition, NECG provides input to literally hundreds of commercial guidance publications that include engineering and technology. But many guidance counselors know little about career opportunities in engineering technology. And much of what they do know seems to be outdated or derived mainly from media comments and portrayals.

Perhaps the chief problem confronting technical education as a career choice is the general lack of understanding of the associate degree. Parents, educators, and students identify the baccalaureate degree as the key to success in life. Compounding this are salary surveys that consistently confirm the financial advantages of higher degrees. Little is publicized concerning job satisfaction, working conditions, and outlets for creativity—all of which do not automatically follow receipt of a 4-year degree.

Students must be reminded, too, that a technical education is but a start in one's career course. Cooperative programs provide experiences that familiarize students with actual work conditions, practices, equipment, and problems. This facilitates the transition from school to work and gives the student a chance to rectify shortcomings in his/her preparation. Despite the operating expense, cooperative education experiences receive almost universal praise from students and employers.

When one considers that technology and its career opportunities are constantly expanding, increased support, especially from business and industry, should be forthcoming to the institutions entrusted with training the technical workforce. The forms of this support and cooperation are explored next as policy options.

Policy Options

In this concluding section, several specific policy options are proposed. Each is discussed with reference to one of the four institutional actors introduced above—professional associations, industry, educational institutions, and Government—who are seen as the loci of initiatives for fostering, coordinating, and implementing action among the producers and employers of the technical workforce.

Professional Associations

Because engineering-based associations are most sensitive to trends and needs occurring in technician/technology training, they are in a key position to inform, debate, and exert policy pressures on both the educators and the employers of the technical workforce. But the empirical basis for such action lies in the collection, analysis, and dissemination of manpower statistics. Building on the efforts of the National Society of Professional Engineers and the Engineering Manpower Commission to monitor the production of technology associate, baccalaureate, and master's degrees, professional associations should act as information clearinghouses. They can focus attention on industry needs, especially sectoral and geographic differences in opportunities for technician/technology specialties. Developing data through employment surveys on supply and demand is an immediate need; augmented job task inventories would clarify, over the long term, job titles and descriptions, prerequisite skills, and career paths.

A continuing function, too, is the provision of guidance information about technical careers. Professional associations recognize that the maintenance of technical skill is as much a problem as maintenance of equipment. As products become obsolete, so does the workforce that designs, makes, sells, installs, tests, and services those products. Thus, as production changes, so must state-of-the-art technical training. Accreditation exerts influence here, as do professional associations. But they can do more, namely, by acting as a broker between the principal institutional actors to bridge gaps and identify strategic points of articulation.

Industry

Industry should invest boldly in underwriting technical education—especially equipment, time-shared personnel, and cognitive inputs to curricula. They would be doing this for their own good. For only by blurring further the distinction between education as pursuit-of-degree and training as on-the-job work experience will industry spare itself the later expense of extensive retraining. Nevertheless, bringing the job into the classroom is no small feat. It requires an outreach effort that identifies a service area in which educational institutions are willing to engage in cooperative internship programs. Inasmuch as faculty shortages, equipment deterioration, and crowded facilities are common today in technology schools, such industry initiatives should indeed be welcomed.

Industrial subsidy of technician/technology training could emulate the "academic-industrial" model occurring in bioengineering and microelectronics.[12] High-technology corporate sponsors are donating equipment, providing matching funds, sharing laboratory facilities, offering personnel as part-time faculty, and contributing student fellowships and loans. These are innovations that are becoming necessities. They carry inducements of cost-effectiveness and rejuvenation of personnel, while redefining the boundaries separating institutional actors. Given economic realities and the pockets of successful cooperation between education and industry throughout the United States, the earlier and more salient introduction of industry to the training process looms as a basic remedy.

Educational Institutions

The reciprocal role that educational institutions should play if industry initiatives are to succeed should be obvious. If such relationships are seen as partnerships, with industry supplying most of the financial capital and education most of the human capital, everybody profits.

Technology education is still largely dependent upon engineering school graduates for its teachers. The limited number of baccalaureate (8,469) and master's (30) degrees in technology in 1981[13] severely restricts the pool of potential instructors for technology schools. Industry represents a source of skilled part-time faculty. In addition, active industrial advisory committees should become an essential element of every technician curriculum. Institutions offering technology curricula need to have the capability of revising, updating, initiating, or phasing out programs. The Accreditation Board for Engineering and Technology contributes to this review process. Yet, at present, obsolete curricula continue for years while new ones are deferred because institutional procedures promote conservatism. Institutional response time can often be cut by using computers and instructional modules in the educational approach and by creating departments where emerging technologies can be tried with experimental curricula, cooperative education, and even temporary faculties.

Finally, good students are attracted to careers that afford opportunities for advancement. To ensure a supply of quality associate degree technicians, it is therefore advisable that 2-year programs articulate with 4-year baccalaureate technology programs. About 20 percent of the associate degree graduates go on to advanced technology degrees. About 50 percent will seek to advance their education at some time later in their careers. This "career ladder" could be reinforced by formal agreements between associate degree and bachelor degree institutions. (In state university systems, unfortunately, this has been difficult to achieve.) The career ladder begins in high school with vocational education tracks. Here, the math and science content must increase so that graduates of vocational programs will be able to raise their aspirations upon graduation from high school and enter a technician program in a high-technology field. In sum, the evidence that students enter vocational programs primarily because of perceived job status and intrinsic interest, and not because of academic ability,[14] should be heeded by technology educators.

Government

The Federal Government has an interest in the development of the technical workforce for the defense and productivity of the Nation. Indeed, Washington should maintain those programs that contain incentives for cooperative funding involving nongovernment actors. One way is through small matching fund grants that could be made available for instructional laboratory equipment. The other half of the match could be provided by either industry, a private foundation, or the educational institution, given that the technology program is being consistently supported by institutional capital equipment funds. That way, the new funds can make a significant difference.

Perhaps the greatest short-term assistance that the Federal Government can offer is the dissemination of guidance information on technician/technologist careers within the Federal Government itself. Civil service classifications for technicians and technologists should be refined in such sources as *The Dictionary of Occupational Titles*, *Occupational Outlook Handbook*, and *Occupational Census Data*, and then "advertised."

The brunt of Government action, however, should occur at State and local levels. For example, recent efforts in ten States to make legislators aware of the dimensions of the engineering education crisis resulted in special appropriations in excess of $40 million of aid. In four States, differential pay increases were approved and implemented for engineering faculty members—an achievement long believed to be unattainable. Unfortunately, technicians and technologists have not achieved a similar level of organization for engendering aid to their type of education.[9] In State university systems, it is difficult to convey the equipment, staffing, and per-student instruction costs to legislatures and boards of regents dominated by a "liberal arts" or, conversely, a "Proposition 13" mentality.

There are several specific actions that State and local governments should consider. First, they could earmark more educational funds for instructional equipment in technology. These funds could then be awarded to technology departments as line items in the budget for equipment or made available for State equipment grants in response to solicited proposals. Second, State boards should monitor institutional responsiveness to the rapid changes inherent in technical education. Curriculum innovation should be encouraged, especially in those institutions that regularly undergo periodic external (ABET) accreditation review by specialists. The awarding of Associate in Arts (AA) degrees in technology by vo-tech schools will intensify competition among accredited and State-funded 4-year technology institutions already laboring under severely strained budgets. Third, State boards should also encourage articulation between high school vocational programs and higher education technology programs. A career ladder approach to developing a highly qualified technical workforce should be exploited. High school vocational programs should provide the option of entry into college technical programs. Associate degree programs should not prevent graduates from transferring, with advanced standing, to baccalaureate degree programs in technology. Graduate programs in technology, as opposed to engineering or education, should be carefully nurtured to provide a stream of faculty for technology programs at levels commensurate with local and regional industrial needs.

Policy Conclusions

State agencies, in concert with national professional associations and their local chapters, can act as catalysts to facilitate interaction among all institutional actors on topics of mutual interest: educational programs, employer needs, occupational titles, faculty qualifications, and equipment needs. Through such interaction, the training and utilization of engineering technicians and technologists will be fully appreciated as a policy issue distinct from, but integrally related to, the productivity of science and engineering manpower in the United States.

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National Security Controls and Scientific Information

Abstract

As part of a broad effort to stem the outflow of U.S. technology to the Nation's military adversaries and to maintain our technological lead, the Government appears increasingly willing to restrict the dissemination of scientific research information to foreign nationals at scientific conferences, in American classrooms and laboratories, and through publication. The research community, both academic and industrial, has expressed serious concern about the substance and procedures of those restrictions, about recent enforcement practices, and about the process by which the rules of the game are established.[1]

The issues posed are difficult and complex, and their resolution requires a clearer definition of our national security objectives. It also requires a clearer understanding of whether the various controls now in use or under consideration will be effective in preventing a loss in America's technological lead over the Soviet Union and can be administered without imposing unacceptable economic, administrative, scientific, or political costs on American society. It is likely that broadly drafted rules of general applicability will generate more serious problems than those that can be refined on a case-by-case basis, tailored to the particular setting and the particular technology. More specifically, it appears that export controls on scientific information are not likely to be cost-effective. Although somewhat greater use of the Government's authority to classify Government-owned or Government-controlled information or to deny foreigners access to the United States might be appropriate, it appears that enhanced dialogue between the Government and the scientific community and increased reliance on contractual restrictions in federally sponsored research offer the greatest promise of success.

Introduction

Advanced technology underpins the Nation's military strategy and its economic strength. Our military strategy depends on maintaining technological superiority to counter the quantitative superiority of the Warsaw Pact nations; our trade position, heavily reliant on the export or domestic purchase of goods and services involving sophisticated technology, depends on maintaining a technological advantage over current and potential commercial competitors. Both depend primarily on creative scientific research and continuing technological innovation and leadership. But both also depend on denying, or delaying the transfer of, some of that new science and technology to certain users and for certain purposes. Because rapid scientific and technological progress flourishes best in an open environment, there is a constant in-built tension between creation and suppression.

Laws and regulations restricting the dissemination of scientific and technological information for national security reasons have existed for many years. Classification and restrictions on the export of technical data have been well-established features of American society since World War II. Such controls, however, were traditionally applied to a very narrow range of scientific information. Four interrelated developments have both spurred efforts to apply controls more broadly and made it more likely that such controls will seriously affect American science and technology.

First, America's relative strength compared to that of its allies and of its adversaries has changed substantially. In the early postwar period, the United States, undamaged by the war, had both an overwhelming commercial advantage and a parallel technological advantage resulting from the wartime effort within the United States and the inflow of talented scientists who had fled Hitler's Europe. That economic and military position has eroded. Where once a unilateral U.S. decision to withhold goods or technologies from the Soviet Union might have been effective, today the successful imposition of national security controls requires the cooperation of our allies, principally through the Coordinating Committee (COCOM). Similarly, where three decades ago American science and technology were supreme and substantially self-sufficient, today American science, technology, and industry frequently rely on the knowledge—and the manpower—of other nations. This relative erosion of American power and an accompanying perception of vulnerability seems to have increased the Nation's urge to control even as its ability to do so unilaterally declined.

Second, technology export is more frequently perceived as an important contributor to America's military and commercial vulnerability. The Government is increasingly concerned that purchased or stolen American technology is an important component of Soviet military strength. Large segments of American society believe that unwise technology exports have accelerated commercial competition both from industrialized nations such as Germany and Japan and from advanced developing nations such as Taiwan and South Korea. Those who advocate stricter national security controls may make common cause with those whose principal concerns are commercial, thereby blurring the important distinctions between the two sets of concerns.

Third, as pressures to control information increase, some have begun to question the long-accepted premise that unclassified, nonproprietary research in general and university-based research in particular would not be controlled except in the most unusual circumstances. Although all agree that most university research raises no national security concerns, many universities are now perceived as doing the kind of applied research once found only in commercial or governmental laboratories, and even basic research is more likely to be seen as having near-term applicability. Recent acceleration of industry/university cooperation in a number of fields, important to continued technological advance, contributes to this perception. If university research resembles other research, there is a strong argument that it should be similarly controlled.

The last major development, closely related to the weakening of American technological supremacy, is the increasingly international face of science and of the American research community and the heightened role of the multinational corporation. Over 40 percent of all citations found in U.S. journals are to foreign publications, and large numbers of collaborative research projects cut across national boundaries.[2] The American campus is similarly international. In some fields, almost half of all doctorates are awarded to foreigners[3]—many of whom then obtain immigrant status and work in either academia or industry. The R&D efforts of many corporations reflect both the increasing multinationalization of corporate activities and the international complexion of recent degree recipients.

The Nation's military and commercial position will continue to be challenged in the years ahead. Concern about the loss of scientific and technical information is therefore also likely to persist. Such concern, however, does not lead to a single, obvious policy solution. The dissemination of scientific and technical information occurs in a multitude of ways ranging from espionage to publication in the open literature, intrafirm discussions, patent applications, or scientific conferences; a single form of control is unlikely to be equally effective for all types of dissemination. Although building for several years, the current debate about the control of scientific information was thrown into sharper perspective by application of export controls to scientific conferences, and much of the debate since has focused on export controls. There are, however, a number of other mechanisms that have been or can be used with greater or lesser effectiveness to stem technology outflow. This paper reviews both export controls and those other mechanisms. First, however, it examines some of the specific reasons, beyond the developments outlined above, why Government and the scientific community are concerned and asks some fundamental questions about what technology needs to be controlled.

Trends and Developments

The question of whether increased Governmental restrictions are needed or acceptable must be judged in light of the threat to American security and to American society. In judging the threat, it should be remembered that while the Soviet Union has undoubtedly acquired much advanced American technology, almost all has come through normal commercial channels, diversion from legal sales, or espionage. Little has come from normal scientific communication.[4] The Government, however, worries that the improper dissemination of certain state-of-the-art scientific research, even if occurring rarely, could seriously damage the Nation's military position. Beyond that, many in the Government fear that in the future the Soviets will more consciously exploit the openness of the research environment to acquire advanced technology.[5]

Just as the Government worries about the future as well as the present, so too does the scientific community. So far, the export control laws have had only limited impact on the research community: the present regulations provide considerable latitude for most exchanges of information with countries other than the Soviet Union and its allies, and they have only occasionally been applied to scientific activity. A greater impact, however, appears to be in the offing for at least two reasons.

First, researchers are becoming increasingly aware that a potentially controlled "export" takes place when they discuss their research with foreign colleagues here or abroad, mail an unpublished paper to a foreign scientist, present a paper at a symposium with international participation, or hire foreign graduate students to work on an advanced research project. Such awareness enhances the likelihood of compliance and therefore of affecting research. Additionally, recent increases in the number of foreign graduate students, faculty, and researchers on American campuses of course mean that the export rules apply more frequently.

Second, controls may in fact be tightened. Some see this as having happened already, pointing to enhanced enforcement of existing export control laws and last winter's well-publicized but perhaps misinterpreted revision of the Executive Order on national security classification. Others simply forecast greater restrictiveness, citing the suggestion of the then Deputy Director of the Central Intelligence Agency that broad prepublication clearance might be required.[6] The Government's visible difficulty in narrowing and refining the scope of the Defense Department's Militarily Critical Technologies List (which will be the core of the Nation's control system in the years ahead) is also a sign of future restraints.

Uncertainty about the present and the future begets worry. The absence of specifics also hampers rational debate. Although the recent report of the National Academy of Sciences (see reference 1) greatly enhances the likelihood of useful and collaborative discussion among the Government, industry, and academia, it is not yet clear how the Government will answer several questions and how it will reconcile competing interests.

Fundamental Questions to be Answered

Export controls on scientific information are currently the main focus of attention. To clarify their applicability or to assess alternative mechanisms, the Government must address four fundamental substantive questions: How should "national security" be defined? What destinations call for controls? What technologies will be controlled? And, what forms of exchange require control? It should also address the procedural question of how the rules of the game are adopted or modified.

Defining "National Security"

If national security controls are to be bounded, "national security" must be defined. It is, unfortunately, an elusive term, used in many senses. It can refer to short-term military strength; it can also refer to the Nation's long-term strategic, political, and economic position in world affairs. Current law is relatively clear that "national security controls," in contrast to foreign policy controls, are to focus on those exports that contribute significantly to the *military* potential of our adversaries. That, however, does not entirely delimit the reach of national security controls. Soviet military strength, like that of the West, depends on both a military establishment and an underlying industrial economy. Exports that bolster the Soviet economy therefore enhance Soviet military capability in the long term. It is widely believed, however, that controls focused on long-term Soviet economic strength are likely to be neither successful nor cost-effective[7] and that national security controls should therefore concentrate on short-term military consequences. However, even if one accepts this short-term military focus, there is, as will be discussed below, the further practical difficulty of delineating those civilian goods and technologies that are militarily relevant in the short term from those that are not.

Geographic Scope of Controls

Scientific exchange and technology transfer within the non-Communist world are largely uncontrolled unless they involve military or nuclear goods or data, or classified information. Under the International Traffic in Arms Regulations (ITAR), military goods and directly associated technical data as well as all classified information to all foreign destinations are strictly controlled; exports to most Communist-controlled nations are forbidden entirely. However, only a relatively small percentage of U.S. exports, and an even smaller percentage of exported scientific information, falls within the scope of these controls. Export of most U.S. goods and technical data is controlled instead under the Export Administration Regulations (EAR). Under these regulations, national security controls seriously restrict technology exports only to the Soviet Union, Eastern Europe (excluding Yugoslavia), the People's Republic of China, and a group of smaller nations (including Laos, North Korea, Vietnam, Kampuchea, and Cuba). Although goods and technology that are controlled for export to Communist nations are also controlled to non-Communist destinations, controls on such non-Communist destinations are generally designed only to prevent transshipment or re-export to Communist nations, not to prevent the original export.

The volume of exports to Europe, Japan, and Third World nations makes any requirement of specific Government approval of each transaction wholly impractical. Imposing such a requirement would in practice ban most exports by making them prohibitively expensive in time and money. Moreover, limitations on what can be freely shared with Western Europeans and others in the non-Communist world without Government permission would require far-reaching changes in the nature of American society (including its campuses).

No such requirement for specific Government approval of all technology exports exists. The Export Administration Regulations provide several mechanisms that effectively exempt many transactions from any requirement of specific Government approval and many other transactions from the requirement of case-by-case Government approval. All published technical data and most unpublished scientific and educational data are covered by one of the General Licenses and therefore require no specific Government approval. Technical data that do require specific Government approval (in the form of a Validated License) may be eligible for a "bulk" license (for example, a Project License) which can cover multiple transactions. General Licenses effectively exempt most fundamental scientific research—and therefore most academic research—from the need for specific Federal authorization. General Licenses together with bulk licenses provide similar freedom for most corporate exchanges of scientific research and technological applications in the non-Communist world.

The system nominally controls almost everything, but in practice requires specific licenses of much less, and actually prohibits the export of very little. The critical question for the future is whether technology transfer within the non-Communist world will remain so unrestricted. It is an important question for at least two reasons. First, the scientific and technological links among the non-Communist nations—and particularly among the industrial nations—are far stronger and far more central to day-to-day scientific and commercial activities than technology transfers with most Communist-controlled nations. For example, while almost half of all U.S. engineering doctorates in 1980 were awarded to nonimmigrant aliens, only .3 percent of those aliens were citizens of the Soviet Union, Eastern Europe, or the People's Republic of China. Industrial employment experience is presumably similar. Given current strains within COCOM, U.S. attempts to control more technology may simply lead to greater U.S. isolation from friends and foes alike.

Second, while many Americans have accepted the need for stringent controls on technology transfer to the Communist world, the imposition of meaningful controls on transfers among non-Communist nations—or West-West transfers—could undermine the existing consensus that national security controls are legitimate and sensible public policy. Within the United States, such controls on West-West transfers would likely be met with considerable skepticism; within other industrialized nations, such controls might be perceived as yet another nontariff barrier, as commercial policy draped in national security bunting.

Substantive Scope of Controls

Under the current rules, unpublished technical information may require Government export approval either if it is directly related to an item on the Commodity Control List or the Munitions List or if, under Part 379 of the Export Administration Regulations, it relates directly and significantly to *any* industrial process. All published and other unpublished technical data are either legally or practically uncontrolled.

The current scope of controls on technical data has been widely criticized, principally on two counts. First, it is argued, much of only marginal national security importance is controlled and thus needlessly subjected to cumbersome and expensive bureaucratic procedures. Although this is also a problem for hardware, such overbreadth is particularly acute for technical data, because Part 379 of the EAR excludes from the most liberal General License much unpublished technical data relating to industrial processes regardless of the national security importance of the processes. And despite continuing efforts to rid the control lists of goods or technology that are widely available abroad, the lists remain long and complicated.

Second, as all agree, the current scope of controls is simply not well understood. This is in part because the technical data regulations—and particularly Part 379 of the EAR—are almost incomprehensible to the average reader. More importantly, both the perception of overcontrol and the fact of incomprehensibility stem from a lack of consensus about what should be controlled. The congressionally mandated Militarily Critical Technologies List was supposed to determine the scope of controls. Following the recommendation of the 1976 Bucy Report[8] that controls should focus on technology and manufacturing know-how rather than on hardware, the 1979 Export Administration Act instructed the Defense Department to develop a list of critical technologies "which, if exported, would permit a significant advance in a military system" of countries subject to national security controls. Subsequent efforts to construct such a list reflect a continuing and unresolved tension between advocates of a very short list of patently critical technologies and advocates of a much longer list including most modern technologies that undergird any advanced industrialized economy. The obstacles to consensus include not only differing concepts of national security, but also the nature of many advanced dual-use (i.e., civilian and military) technologies and the difficulties of reducing general conceptual agreement to regulatory language.

Computers are an example of a dual-use technology. In the United States, most major industries—and probably all militarily significant industries—use computer technology in all aspects of the life cycle of a product: definition of product requirements, development and design, production and operational support, and utilization. Computer-Aided Industrial Process Control (CAIPC) technology, even when developed for purely commercial uses, provides a strong mobilization base by permitting the rapid conversion of industrial capacity from civilian to military uses. The same is true of Computer-Aided Manufacture and Test (CAM/CAT) techniques. Both CAIPC and CAM/CAT illustrate the difficulty of drawing the line between controlled and uncontrolled technology. First, both techniques are strategically important, but both also have broad commercial application: much, if not most, of the research and development related to these technologies is being done by the private sector for its own use. Particularly because American manufacturing leadership may depend on sophisticated factory automation, efforts to control the dissemination either of the technology or of the products embodying it would have immediate and important trade consequences.

Beyond that, the Government's own use of these technologies depends in good measure on their development by the commercial sector. And that development depends importantly on university-based fundamental research in a wide range of scientific fields (including dynamics, stress analysis, computer architecture, computational techniques, and microstructures), where the lag between basic research and commercial application is likely to be very short. Restrictions that discourage academia from working with industry in these areas will therefore have important national security as well as trade consequences.

Translating into regulatory language the limited consensus that does exist about what should be controlled has also been a problem. For example, although there is wide agreement that most fundamental research should not be controlled, defining "fundamental research" is difficult. The Export Administration Regulations speak of scientific and educational information not "related directly and significantly to design, production, or utilization in industrial processes." Executive Order 12356 on national security information speaks merely of "basic scientific research." This implied distinction between basic and applied research is not helpful, because whether a given research result is basic or applied depends both on the purpose of the research and on the judgment of the observer. If publishing generic definitions of what is controlled runs into insurmountable definitional problems, publishing specific guidance runs head on into the "blueprint problem." If Government defines specifically the line between fundamental research that need not be controlled and other research that may require controls, that definition provides a great deal of information about American technological capabilities and the Government's strategic concerns. Publishing it might therefore give our adversaries a "blueprint" of those technologies of greatest importance to the United States and allow them to reallocate their own R&D resources into more promising areas. Deciding what technologies need to be controlled in the future will take time; translating that decision into regulation will be yet more difficult.

When does technology transfer take place?

The fourth question asks, What exchanges of scientific information effectively transfer technology? Those that do not, need not be controlled. (Of course, not all effective transfers should be prohibited even to our most serious adversary. Most scientific exchanges work in two directions. Therefore, once it is determined that a technology loss is likely, it is also necessary to judge whether there will be an offsetting technology gain. If there will be, the exchange should usually be permitted.) Ordinary, though perhaps difficult, observation can establish whether a given piece of hardware has been transferred to an adversary. It is much harder to tell when technology has been transferred. Whether technology transfer takes place in a given situation depends on the nature of the information, the skill and training of the giver and the receiver, and the nature and duration of their interaction.

For some technical information, simple possession is enough. Steal the recipe and you should be able to produce a reasonable imitation of Coca-Cola. Although there are important exceptions, the theft of blueprints for hardware to be produced abroad is generally not the principal national security concern today. That kind of technological piracy will usually assure preservation of American leadtime, precisely the objective of controls. Similarly, while the simple knowledge that something can be done may occasionally be the problem, more usually the concern today is whether an adversary will be able to apply sophisticated scientific and technical principles and information to its own needs and then build further on them. Occasionally, a casual exchange will transfer a critical concept or important piece of information. More frequently it will not. As the Bucy Report concluded in 1976 and as American foreign aid programs learned through hard experience, effective technology transfer does not occur casually or quickly. Rather, it requires that the giver and the receiver actively interact with each other over a sustained period of time.

Despite wide agreement on this point, current export control regulations on technical data generally do not distinguish "exports" that will transfer technology effectively from those that will not. An hour of formal presentation of unpublished research findings to a small group that includes foreign scientists or a quick walk-through of a laboratory containing advanced computer equipment are as likely to fall within the scope of controls as an intensive training program. As a result, specific approval is required for many "exports" to Communist countries that most agree to be harmless. And once within the scope of controls, there are no clear and publicly known criteria to guide the Government's decision when to approve or disapprove a license.

Designing the Rules of the Game

Much of the scientific community's concern arises from its conviction that the Government cannot properly assess the scientific and educational costs of various kinds of restrictions because of inadequate input from the scientific community itself. While it is generally undesirable for large segments of the American populace to feel excluded from the Government's decisionmaking process on issues of importance, it is particularly unfortunate when the Government must rely in great measure on voluntary compliance and cooperation rather than on legal compulsion. It is therefore important for the Government to address the issue of how the scientific community can most productively participate in establishing the system under which all must live.

In short, there is still no national consensus about how broadly to define national security; what destinations require control; how many technologies should be controlled; what kinds of research, if any, warrant controls and how the line between controlled and uncontrolled is to be drawn; and what kinds of exposure to American technology are sufficiently detrimental that restrictions are likely to be cost-effective. Neither is there a clear mechanism for attempting to build that consensus.

Assessment of Control Mechanisms

These questions would be difficult to answer even if export controls were the only way to restrict scientific information. They are not. At least four other control tools have been used in the past and could be used more in the future: national security classification; stricter use of the Government's visa authorities to deny or set conditions on the admission of foreigners; contractual restrictions for research performed with Federal funding; and various forms of voluntary self-control.

Without agreement on what a mechanism should control, it is hard to decide what control mechanism to use. For example, mechanisms designed to deny the Soviets a mere handful of technologies may be grossly inappropriate if the policy is to deny a larger number of nations a broad range of technologies. On the other hand, these mechanisms have different characteristics and impose different costs on American society. It is difficult to know what to control without knowing the costs of controlling it, and that depends on the mechanism used. It may be useful, therefore, to analyze the merits and demerits of the mechanisms.

Many criteria are relevant. Four clusters, however, appear to be most important:

(1) *Effectiveness*. Will the system accurately identify what needs to be controlled, and will there be sufficient American and COCOM cooperation that it can be enforced? Alternatively, if COCOM cooperation is not likely, will unilateral controls merely isolate the United States?

(2) *Administrative and Economic Burden*. Can the system be administered without imposing unacceptable administrative and economic costs either on the U.S. Government or on the American population? Can the procedures be simplified and the uncertainty reduced?

(3) *Scientific/Technological Costs*. Can a system be designed that avoids substantial slowing of scientific or technological progress—whether by compartmentalizing research into controlled and uncontrolled areas, by further hindering industry/university cooperation, or by damaging the intellectual climate?

(4) *Political Values and Consensus*. Can a system be designed and enforced that is generally accepted by the American population as a reasonable and legitimate response to a shared threat? Will industry and academia perceive the Government—particularly the national security agencies and those charged with enforcement—as an adversary or as a partner in a collaborative effort? Muting the current adversarial climate will

require not only public understanding of the nature of the threat, but also public acceptance that the means adopted are lawful, predictable in their application and enforcement, and appropriate to the magnitude of the problem.

Clearly, these clusters are related. A system built on domestic political consensus is more likely to be effective in stemming technology outflow. A consensus is easier to build if the system is seen as effective, as administratively efficient, and as imposing the minimum possible cost on other social values. However, while all four clusters are important and need to be considered, this discussion emphasizes the effects on science and technology.

Export Controls

Export controls that reach scientific information unrelated to a commercial transaction or only remotely related to a controlled commodity fare badly when judged in terms of either effectiveness or political acceptability. They are too broadly and imprecisely defined to give Americans a clear understanding of proscribed conduct; in addition, a number of COCOM members are unwilling to control such "disembodied" technology. Further, because of the complexity and breadth of the rules, administration is cumbersome, compliance costly in dollars and time, and enforcement difficult.

While ineffectiveness alone would be enough to undermine a political consensus that controls are valid and legitimate, the problem is exacerbated by the increasingly widespread belief that controls on such "disembodied" technology are unjustified infringements of constitutionally protected First Amendment rights. Both the Justice Department and a U.S. Court of Appeals have raised serious questions on that issue. The Justice Department addressed these issues twice, first in a 1978 Memorandum to the Science Advisor[9] and again in a 1981 Memorandum to the Department of State.[10] On both occasions, Justice stressed that prior restraints such as those represented by the ITAR and EAR licensing systems will be upheld only upon a governmental showing of grave danger to the Nation and concluded that the regulatory scheme under review "cast such a broad regulatory net" through a system of prior restraint that it was "presumptively unconstitutional." The Ninth Circuit Court in *United States v. Edler Industries, Inc.*,[11] a criminal case, also strongly suggested that restrictions on technical data would be constitutionally acceptable only as long as the data were significantly and directly related to specific articles on a control list.

On the other hand, because so much information is practically uncontrolled for most destinations and because enforcement has been limited, export controls to date have had little direct impact on progress in science and technology. Tighter restrictions would presumably affect science and technology much as classification has done (see below). The more these controls are used, the less benign their effect.

Classification

Since World War II, the Government has used its classification power to control certain kinds of scientific information. The advantages of classifying information are clear. Although classification requires defining *what* needs to be controlled on a case-by-case basis, the question of *to whom* is clear. Only those with a security clearance and a "need to know" may receive classified information. Denying information to almost everyone is an effective means of denying it to one's adversaries.

Perhaps because the limitations are so severe, relatively little scientific information has been classified. As a result, although there are serious administrative costs to working on classified research (as well as some disputes about what is classified), those costs are imposed only on a small segment of the scientific community rather than on the population at large. The Government's relative self-control in classifying scientific information has also created an aura of legitimacy, which itself encourages compliance.

Classification's effectiveness in denying information to adversaries is bought at the price of denying it to nonadversaries—scientific colleagues, for example. Its effects on scientific and technological progress are therefore quite severe.

Classification divides—or compartmentalizes—the scientific community into those with clearance and a need to know (which frequently includes nationals of the North Atlantic Treaty Organization and other friendly countries) and those without. As the United States learned from the experience of atomic energy, intellectual exchange between the two camps is limited. The normal processes of collegial criticism, of learning from the successes and failures of one's peers, and of using research to train the next generation of scientists are all impeded. Restrictions on publication may make working in a classified field less attractive, so it may be difficult to recruit and retain people in the areas of greatest national security need.

The divisive effects of more extensive classification are likely to be even greater now than during the early Cold War period, due to the lingering effects of Vietnam. Many major American research universities prohibit classified research on campus. Off-campus classified research is detached from mainstream university activities; student participation is minimal. These policies are not likely to change soon. Therefore, those attracted to academic life will likely avoid work in classified areas.

With classified research thus largely confined to industry and Government laboratories, close collaboration between scientists in industry (who will do classified research) and those in academia (who will not) may be impeded. If so, industry will be decreasingly able to rely on the academy to generate well-trained talent in relevant areas, to perform nonproprietary research of interest to industry, and to provide greater access for its researchers to current international scientific thinking. A parallel result could be further separation of academic science from national security issues, from mission-related research, and from research of direct relevance to emerging industrial needs, because most of the technologies of national security concern have commercial applications.

The simplicity, clarity, and precision of classification are its great strengths. Atomic energy information may be "born classified," but in other areas the Government must affirmatively and unambiguously decide to classify information. Even in atomic energy, disputes over what is classified have been relatively manageable. These strengths also engender problems. Unless the Government classifies an entire broad field, like atomic energy, classification decisions are unending. Further, assuming the Government wants to classify information *before* it is generally disseminated, it must somehow shift some of the burden of identifying potentially classifiable information to the scientists who generate it. That may not be too difficult for research performed in Government laboratories. Scientists there are likely to be aware of possible national security ramifications of their research and, like some industrial researchers, are more willing to accept publication and other restrictions as conditions of employment.

However, as the controversy generated by Executive Order 12356 on national security information attests, identifying potentially classifiable information will be much harder for private sector research. First, and probably most serious, there is the problem of defining what may require classification. The term information "relating to the national security" has no self-evident meaning, particularly for people not in daily contact with national security issues; all the uncertainties of the current export control laws would re-emerge here. Second, people outside the Government and not working on Department of Defense contracts do not expect their work to be classified and do not consider classification an occupational hazard. Prepublication Government review of as yet unclassified research, especially when not federally funded, suggests censorship to many.

Visa Controls

The Federal Government has broad powers to bar aliens from entering the United States or to set conditions on their stay. While the Government may legally bar an alien to avoid an undesirable technology loss, visas are rarely denied on that ground. Intelligent use of the visa authority requires generalized answers to the questions of what technology needs to be controlled, to whom, and in what form. Without them, case-by-case review of all requests for nonimmigrant visas would bring the entire process to a halt. Intelligent use also requires more information than is now typically available for nationals of some countries. While costly to collect, that same information is required to selectively implement *any* form of control.

Denying a visa usually keeps an alien out of the United States. But it prevents technology transfer only if the visit was essential to an effective transfer. For someone who intended to come as a degree candidate or postdegree researcher, the denial probably does prevent transfer. For someone who would have come for a very short stay, for a symposium, or to hear a paper delivered that will soon be published in the professional literature, the denial probably does not bar transfer (particularly if Americans may freely convey the same information at conferences and symposia abroad and there are no restrictions on domestic publication).

The private sector generally finds visa denials or restrictions attractive, particularly when contrasted with a governmental suggestion that the export control laws make universities in some way responsible for ensuring that legally admitted aliens are denied access to controlled but unclassified information. Such an interpretation of the export control laws would require universities to assume a role for which they are temperamentally and physically ill-equipped, namely, that of monitoring the activities of their students, researchers, or visiting faculty and restricting the access of some merely on the basis of nationality. In contrast, governmental use of visa denials requires the Government to shoulder most of the administrative burden and avoids conflict with strongly held val·:es.

Visas as a control mechanism have certain attractions for the Government as well. While broad criteria can (and should) be publicly stated, decisions on individual applications can be made by the State and Justice Departments behind closed doors in consultation with the national security agencies. The Government therefore does not have to fully explain why a particular visa was denied and, when it does explain its reasons, can do so outside the glare of publicity. Definitional and "blueprint" problems, linked to the publication of criteria sufficiently detailed to guide public beha need not arise.

In general, relatively small numbers denials or restrictions, particularly if li to nationals of countries that are proscribed under the export control laws, appear unlikely to have major consequences for science and technology (although there may be foreign policy concerns).

Special problems, however, are likely to occur when the foreigner is requesting a visa to attend an international scientific conference sponsored by the International Council of Scientific Unions (ICSU). Because ICSU policy prohibits adhering members from holding conferences in countries that deny entrance to bona fide scientists, a U.S. visa denial may only serve to force such conferences abroad and isolate Americans from their scientific peers. Such a possibility should clearly be considered when the Government weighs whether, on balance, the attendance of the scientist or scientists in question will result in a net technology loss to the Nation.

Granting or denying aliens admission to this country is clearly an appropriate governmental function. If visa controls are exercised with restraint, they are unlikely to become a major source of contention. However, closed-door decisions influenced by the national security agencies may have an unhealthy bias toward overconi articularly if information about the benef of the visit is not readily available within the Government. In any event, visa authority cannot be the primary means of control; it is too easy for our technology to be transferred outside our borders by other means. Consequently, visa denials are perhaps best viewed as a way of reducing the objectionable domestic effects of export controls.

Contractual Restrictions on Federally Funded Research

In early 1982, the Report of the Defense Science Board Task Force on University Responsiveness to National Security Requirements suggested greater use of contractually imposed restrictions to avoid some of the uncertainty and contentiousness of other means of control.* For example, a research agreement might limit or require approval of foreign participation or require

*A contract, for this purpose, includes any contractual instrument whether labeled a contract, grant, or cooperative agreement.

prepublication review of research results. Although recommending this now only for the Defense Department, the report suggested that such restrictions be used by other Federal agencies if the need is clearly established. Presumably, contractual restrictions applicable to industry/university collaborative research would bind both industry and university.

With the Federal Government funding almost half of the R&D performed in the United States,[12] contractual restrictions are a powerful tool. Contract clauses are likely to effectively restrict dissemination of the particular information developed under contract. Researchers usually heed contract terms, at least when it is made clear that the funding agency will enforce them. However, if similar or related research is either not federally funded or funded by an agency that does not impose these restrictions, similar information will be disseminated unless it is otherwise controlled. The Government's ability to rely on contractual restrictions thus depends in great measure on whether similar research is likely to be otherwise controlled. The answer appears to be that it is. Industry-funded research (including that on campus) promising clear, short-term commercial applications is usually subject to proprietary restrictions. If the firm seeks a patent, the Government can impose a patent secrecy order. Most other research, while not controlled, is unlikely to be sensitive on national security grounds.

Contractual restrictions impose only limited administrative burdens. Instead of controlling entire fields, as the Atomic Energy Act does, or entire technologies, as export controls may with the Militarily Critical Technologies List, contractual restrictions can be tailored to the particular research project. Areas of concern can be identified quietly and explained to the researcher without risking a public "blueprint problem." Because contractual restrictions are likely to be drafted and monitored by research sponsors, there is reason to hope the restrictions would be reasonable—although guidelines will still be needed to channel the discretion of individual program managers who might otherwise be overzealous.

The effect these restrictions would have on science and technology depends on the way they are used. If they are applied frequently or with a heavy hand, their effects can approach those of classification. Individual scientists will have to decide whether to work in tightly controlled areas. Individual institutions will have to decide whether the conditions are compatible with their philosophy and objectives. The more infrequently such conditions are imposed, the easier it is likely to be for an institution to accept them. If the universities but not industry decline to work on such terms, industry/university collaboration once again becomes more difficult.

The affected public is more likely to accept broader contractual restrictions than most other forms of restrictions, particularly if the restrictions are accompanied by better communication and their permissible scope is clearly laid out in agency policy. As with university decisions to accept delays in publication to preserve patentability in industry-funded research, there is an aura of voluntarism. Because the conditions can be tailor-made, they are more likely to appear appropriate to the situation. Because the negotiations can be conducted privately, the Government is better positioned to explain why the information is sensitive. Because the contract must be signed *before* research is begun, restrictions are less likely to seem arbitrary and unpredictable than those imposed in midstream.

Voluntary Restraint

The term "voluntary restraint" is not consistently defined and two uses are most common. Sometimes, it refers to arrangements, such as those in cryptography, by which researchers voluntarily submit their work to the Government for prepublication review. These arrangements as yet have no legal basis; the National Security Agency (NSA) concluded that it lacked any ground for legal compulsion. At other times, the term refers to the motivation for compliance with legally imposed restrictions for reasons other than fear of penalties. This usage suggests that if the Government did a better job of explaining to American scientists what it was worried about and why, it could apply very tight controls (for example, classification) to only the most critical technologies; alert researchers to other possible problem areas; and rely on their general patriotism to restrict dissemination or seek consultation when questions or problems arise.

Although the Government should do a better job of communicating legitimate national security concerns to the American public (including the scientific community), it would be difficult to rely *solely* on the first form of voluntary restraint for several reasons. First, there are the now familiar difficulties of the "blueprint problem" and administrative burdens. Willing to submit to prepublication review, public-spirited cryptographers asked NSA to define its areas of direct concern; NSA finally concluded that publication of such a list would be more damaging to the national security than publication of the research results. The Defense Department's difficulty in publishing an unclassified version of the Militarily Critical Technologies List suggests that the problem is a general one. If the Government cannot alert researchers to its specific concerns, it could alert them to broad concerns and then scan a huge quantity of voluntarily submitted material. This may be possible in a small, highly sensitive discipline like cryptography. But where the number of researchers is large and the security implications less compelling (or at least less obvious), this broad net approach would be slow, costly, and unlikely to lead to an adequately high level of voluntary compliance.

While perhaps also inadequate as the *sole* Government strategy, the second form of voluntary restraint has considerable merit as an *adjunct* strategy. Most Americans do not want to aid America's military adversaries. If they believe the Government when it says that the release of certain information will be damaging to the Nation, most—despite the importance of publication in the research environment and reward system—will try to find a way to accommodate the Government's concerns. This kind of mutual trust does seem to be emerging in the cryptography field. The Government would be well-advised to try to create it elsewhere.

Better communication, mutual trust, and voluntary restraint may be the only practical or effective way of dealing with emerging technologies that are not Government funded. Clearly the broad approach of export controls is not working; the classification route is also limited to information the Government owns or controls; and contractual limitations too presuppose a Federal financial role.

Policy Considerations

Two general conclusions dominate. First, effective instruments for controlling the dissemination of scientific information would impose great costs on progress in American science and technology (and thus on long-term national scurity). And even ineffective tools, such as export controls, may discourage scientists from working in areas subject to restriction, impose financial and administrative costs on science, affect the research environment, and drive a wedge between the Government and important segments of the population. Indeed, mechanisms that are ineffective because of their broad but uncertain sweep may impose higher costs than effective mechanisms. Second, clear and narrow restrictions that put the definitional burden squarely on the Government's shoulders are more likely to be accepted as legitimate and appropriate Government policy than are broad restrictions that attempt to shift the task of identification to the scientific community.

These general conclusions have specific policy implications for each of the several control mechanisms discussed above. First, it would be both very difficult and socially disruptive to apply export controls more broadly to scientific research. Second, although classification is obviously an effective control mechanism, its costs to science and technology suggest that it cannot be used substantially more frequently without endangering the scientific endeavor that underpins our economic and military health. Third, selective use of visa denials when potential net technology loss is clearly threatened would appear to impose little scientific cost and would probably meet with relatively little scientific hostility. And fourth, contractual restrictions, although not without their dangers, are a reasonable approach. Because specifically negotiated contract terms are more likely to be appropriate than generally applicable export control regulations, the regulations should be revised to make it clear that compliance with federally imposed contractual restrictions—at least when imposed or reviewed by a national security agency—relieves the research performer of further obligation under the broader export control laws and regulations.

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Issues in Scientific and Technical Information Policy

Abstract

The generation, collection, organization, processing, and distribution of scientific and technical information is a significant but neglected area of R&D policy. Rapid technological changes as well as the growing economic and social importance of information in society are making the formulation of policy in this area both necessary and difficult.

Issues related to control of and access to scientific and technical information—including protection of personal privacy and proprietary information, restriction of information flow for national security reasons, and the emergence of international barriers to information flow—are high on the agenda. Heightened awareness of national security concerns has stimulated intense policy debate over the merits of controlling the flow of potentially sensitive scientific and technical information relative to the value of open communication among scientists. Other debates have arisen over the proper U.S. response to economically motivated moves by other countries to limit transborder data flows and otherwise impede the international flow of scientific and technical information.

Another set of issues centers on the economics of scientific and technical information and conflicts between the roles of the public and private sectors in providing information services. Pricing policies of Government information centers have stimulated considerable debate, reflecting policy inconsistencies as well as deep-seated philosophical differences. Some approaches to resolving the issues, based on differentiating types of uses and users, are suggested.

The various roles of the Federal Government in scientific and technical information are highlighted, and a number of options for further examination and action are proposed.

Introduction

Scientific and technical information is a major product of research and development (R&D). The results of R&D projects sponsored by the Federal Government—some $40 billion in fiscal year 1983—are of value only if they can be communicated and put to use. They must be communicated to other researchers whose work is based on the existing knowledge base and who must have rapid access to up-to-date, accurate scientific and technical information to avoid unnecessary duplication of effort, to speed up the process of innovation, and to make best use of limited resources. They must also be communicated to users who can put the findings to work in practical applications—new products and processes for the commercial marketplace, and new programs and policies in the public sector. Yet, for all the attention devoted to R&D budgeting, policymaking, and management, relatively little attention has been paid to information policy in the context of Federal R&D.

Scientific and technical information policy should not be considered in isolation. First, it is clearly an integral part of R&D policy and should be closely linked to decisions on R&D priorities and management. The production, dissemination, and use of scientific and technical information are critical elements in the efficient and effective use of Federal R&D funds. Federal R&D policy must thus be concerned not just with the conduct of the research itself, but with the dissemination and utilization—in both the public and the private sectors—of the fruits of that research. Second, although discussions of it have sometimes failed to acknowledge the fact, scientific and technical information policy is also one aspect of the broader domain of information policy and management. The latter is a domain of growing scope and importance which encompasses such diverse concerns as the operations of computerized data bases, copyright and patent policy, telecommunications regulation, privacy protection, and transborder data flows. The implications for scientific and technical information of decisions made in these realms must be recognized and taken into account in the formulation of R&D policy.

Scientific and technical information is a significant area of economic activity in the United States. King (1981) estimates that nearly $15 billion is spent each year on authoring, publishing, storing, distributing, and using scientific and technical information. Of this amount, the Federal Government is reported to support about 45 percent through direct publication of books, journals, and technical reports; funding of over 200 scientific and technical information clearinghouses, three national libraries and 3,000 other libraries; operation of several national statistical centers and other information activities; and support of scientific communication through payment of page charges and attendance at professional meetings for researchers under grants and contracts. According to King, the Federal expenditures include $1.2 billion a year for library, abstracting, and indexing activities, and $1 billion for numeric databases.

Making information policy is particularly difficult at present. In part, this is a result of the fact that we are becoming increasingly an information-based society and that technological advances are leading to the merging of information and communications technologies. Consequently, society is now faced with a variety of new technological capabilities, some with important social consequences, for which it is relatively unprepared. Another factor is that most segments of the information industry (e.g., data processing) have been essentially unregulated, while communications have been subject to heavy Government regulation. The problems of how to establish appropriate legal and regulatory frameworks for the new, merged technologies are just beginning to be sorted out. Increasingly, also, information is being recognized as a resource—a resource of significant economic value, particularly in an economy shifting from manufacturing to services. The economic importance of the information sector is only beginning to be recognized.

The remainder of this paper reviews briefly a select set of policy issues relating to scientific and technical information. It covers the U.S. policy context, economic issues and the public/private sector debate, access to scientific and technical information, and the role of the Federal Government. The issues discussed here are complex and overlap in many ways. The structure within which they are treated here is but one of many possible approaches to their analysis and discussion.

Policy Context for Scientific and Technical Information

Federal responsibility for scientific and technical information has evolved gradually, often associated with legislation that had neither information nor science and technology as a principal focus.* Each of the agencies that produces scientific and technical information as part of its operations—including the Department of Defense (DOD), the Department of Energy (DOE), the Environmental Protection Agency (EPA), the National Institutes of Health (NIH), the National Library of Medicine (NLM), and the National Aeronautics and Space Administration (NASA)—traditionally has had its own methods and policies for managing distribution and access to that information. The evolution of the National Technical Information Service (NTIS) in the Department of Commerce in the 1960s (formerly the Office of Technical Services, then the Clearinghouse for Scientific and Technical Information), was a major milestone in the development of Federal scientific and technical information activities. NTIS collects, organizes, and disseminates technical reports resulting from Federal R&D contracts and grants. The National Science Foundation (NSF) also has developed many scientific and technical information activities associated with its responsibilities in funding basic

*For a detailed chronology of events and reports related to scientific and technical information, see Congressional Research Service, 1978.

research. They have included supporting research in information science and policy as well as promoting the dissemination of research results by providing seed money for the development of modern, computerized information systems and databases outside of Government, such as Chemical Abstracts Service (1965-75).

The National Science and Technology Policy, Organization, and Priorities Act (P.L. 94-282), under which the Office of Science and Technology Policy (OSTP) was established, includes provisions establishing several advisory groups to provide a more coherent means of managing and disseminating scientific and technical information. Furthermore, the Act establishes the basis for Federal scientific and technical information activities as a part of R&D policy. It specifically states that

> . . .it is recognized as a responsibility of the Federal Government not only to coordinate and unify its own science and technology information systems, but to facilitate the close coupling of institutional scientific research with commercial application of the useful findings of science. (90 Stat. 461)

Despite the explicit recognition, here and elsewhere, of Federal responsibility for the coordination of scientific and technical information policy, most Federal agencies have systems that reflect and support their own needs and missions and are not well integrated into the larger context of scientific and technical information, R&D policy, or general information policies.

It is becoming apparent that existing frameworks do not well accommodate the developing and expanding information and communications technologies, especially with respect to the problems of regulation and public/private sector interactions. Scientific and technical information policy is only a subset of the larger universe of information policy, and policy choices made in relation to emerging electronic or banking systems, for example, may in turn affect policy deliberations more directly related to scientific and technical information. The convergence of computer and communications technologies, developments in storage, processing, and distribution techniques, and the growth of information services in the economy have implications for a wide range of enterprises.

Scientific and technical information policy is often viewed and developed within the context of specific programs or projects. This is in part a reflection of the diversity of interests involved and that no real organizational focus for policy formulation exists. In addition, decisions regarding scientific and technical information generally seem to be made by mid-level program managers who administer these information systems, and seldom involve senior level policymakers who have broader concerns and perspectives.

As the Nation moves increasingly into an information era, as society becomes more technologically oriented, and as changes occur in the direction of R&D efforts, the need to link scientific and technical information policies to R&D policies, as well as to broader information and communications policies, becomes more critical. For example, as civilian R&D activities in the Federal Government focus increasingly on basic research rather than applied research or development, and as defense-oriented R&D receives increasing funding, demands on scientific and technical information systems are bound to shift and Federal programs will need to adapt. At the same time, as the Government reduces its information collection and dissemination efforts—either as a result of budget cuts or such initiatives and laws as the Paperwork Reduction Act—both users and producers of scientific and technical information will need to make some difficult choices. The ability of those involved in scientific and technical information to heighten the awareness of other policymakers to the consequences of their decisions will be a key determinant in maintaining the vitality of scientific and technical information programs as broader policy changes occur.

The United States differs significantly from other nations in its approach to policies affecting information, communications, and R&D. In the United States, the private sector is the basic provider of data processing and telecommunications products and services, the supporter of the major share of the Nation's R&D effort, and the performer of an even larger share. The significance of this arrangement has been highlighted in recent years as policymakers have sought to enhance marketplace competition and increase the "privatization" of Government activities. Even where the Government remains a major player, however, the approach has been decentralized and often fragmented. This is due in part to the traditional U.S. antipathy to centralized planning schemes and the belief that diversity of ideas and open competition ultimately produce the best results.

The U.S. approach contrasts sharply with the approaches of many other nations of the world where governments develop national strategies, target specific industries for support, and control critical elements of the economy. For example, most telecommunications facilities in Europe and Japan are either government-owned or government-operated. Likewise, the French government has recently announced that it will be substantially increasing its R&D spending to promote high technology industries, while the key position of the Japanese in the semiconductor industry is attributed to the role of that nation's government in fostering industrial development.

The fact that these challenges are emerging from abroad does not mean, as some have suggested, that the United States should forsake its ways of doing things and seek to emulate such foreign practices as the Japanese style of management. The strength of the United States lies in great measure in the diversity, independence, and competition of ideas inherent in our way of governing and in our economic structure. The areas of R&D, communications, and information technology are particularly noteworthy examples of this. The importance of the current situation is to alert the United States to the need to acknowledge the differing approaches of our major trading partners and our ideological opponents abroad so that effective policies can be formulated to respond to them.

Economic Issues and the Public/Private Sector Debate

With the increasing importance of the information sector to the U.S. and world economies, and the growing recognition by those involved in the generation, collection, transmission, dissemination, and use of information of its actual and potential value, come a host of theoretical and practical problems. A number of these underlie current policy debates in the area of scientific and technical information.

Pricing Policies

The issue of pricing policy and the attendant issue of unfair competition are raised frequently and applied to several aspects of Government involvement in scientific and technical information. Government scientific and technical information centers vary substantially in the prices they charge for their services. Certain users are not charged at all, while charges to others differ according to each center's policies and the type of user.

General policy guidance on user charges for Government information services is contained in Office of Management and Budget (OMB) Circular A-25, "User Charges," which requires that user charges be imposed when a Government service

> . . . enables the beneficiary to obtain more immediate or substantial gains or values (which may or may not be measurable in monetary terms) than those which accrue to the general public...

This circular establishes the general policy of the Executive Branch that a reasonable charge "should be made to each identifiable recipient for a measurable unit or amount of Government service or property from which he derives a special benefit." The circular specifies that the charge should enable the agency "to recover the full cost to the Federal Government of rendering that service" and must include "the direct and indirect costs to the Government of carrying out the activity," as well as a fair allocation of such items as salaries, research, and supervisory costs (OMB Circular A-25, Paragraphs 3, 5). Under a 1974 Supreme Court decision, however, the recovery of indirect costs is limited to those costs that are actually associated with the specific services provided, and excludes those that benefit the public at large or are incurred in establishing the whole program (U.S. General Accounting Office, 1979: 20).

In a survey of 38 information centers in five departments and agencies, the U.S. General Accounting Office (GAO) found that the centers actually recovered only a small fraction of the costs of providing their services and that, when charges were made, cost recovery policies were not applied consistently. The same GAO report concluded that private firms that purchase Government databases and market the service should be assessed "fair and equitable charges"; failing to do so would result in a general taxpayer subsidy to non-Government users of the service (U.S. General Accounting Office, 1979: 27-29).

OMB Circular A-76, "Policies for Acquiring Commercial or Industrial Products and Services Needed by the Government," revised March 29, 1979, is based on the notion that the Government's business is not to be in business. The circular limits and defines Government competition with the pr... sector, stressing reliance on the priva... for the provision of goods and se...

> In a democratic free enterprise syst...: Government should not compete with its citizens. . .In recognition of this principle, it has been and continues to be the general policy of the Government to rely on competitive private enterprise to supply the products and services it needs. (OMB Circular A-76, Paragraph 2)

Several points are made by critics of current Government cost recovery practices:

(1) The system is inequitable. By not recovering the full costs of services from users, the Government is setting artificially low prices and using general tax revenues to benefit the few (i.e., special interests) who use the information services.

(2) Government scientific and technical information services misallocate resources. Since the services are priced without reference to either their "true" cost or their value to users, the Government has no way of telling whether it is funding the services at an optimal level.

(3) The presence of Government distorts the information marketplace. Government practices (e.g., pricing) affect the supply and demand for information services, make it more difficult for a free private sector market to operate, and threaten the viability of private firms.

(4) Government involvement discourages innovation by creating uncertainty and reducing the rewards for introducing new services and technologies. The same factors hamper the entry of new firms into the field and discourage private sector investment.

Several rejoinders are made to these charges:

(1) Production and distribution of scientific and technical information are part of the statutory missions of many Federal agencies, especially those that operate in R&D-intensive areas. For example, the statute under which the National Institute of Education operates authorizes its director "to conduct educational research...[and] assist and foster such research, collection, dissemination..." Similarly, NASA is required by the Space Act to provide the widest practicable and appropriate dissemination of information concerning its activities and their results. Under broad mandates such as these, agencies have ...urally favored wide distribution of scientific ...d technical information over full cost recovery, since wide distribution contributes to the purposes the agencies are trying to accomplish.

(2) Government scientific and technical information activities serve the public interest in important ways. For example, in discussions of Medline, NLM's online bibliographic service, advocates of the system stress that low-cost access to the medical literature for researchers, students, and practicing physicians yields dividends in improved health care and accelerated biomedical research. These dividends, it is claimed, far outweigh the costs to the Government of providing the services, and are more important than the issue of unfair competition with more costly private sector bibliographic services.

(3) The private sector contains both producers and users of scientific and technical information. It is not coincidental that it is generally the *producers* who see themselves in competition with the Government and who argue most strongly against the Government role. The private sector *users*, on the other hand, who benefit from the Government services, favor their continuation and do not usually regard unfair competition as an important issue.

One major point too seldom acknowledged by either side in this debate is the fundamental difficulty with the concept of full-cost recovery. According to economist Yale Braunstein, the "apparent simplicity and concreteness of the full-cost calculation is entirely misleading" (National Telecommunications and Information Administration, 1981: 67). Braunstein points out that the existence of joint costs (costs that are shared among several products) in any multiproduct organization and the problem of demand elasticities make full-cost recovery an elusive notion. He quotes a pricing manual prepared for NSF to demonstrate the complexity of creating full-cost recovery policies:

> . . .if there are economies of scale or other patterns of responsiveness of costs to volume of sales, demand data will also be needed if the prices selected are actually to end up covering costs. Demand information cannot be dispensed with; for in calculating the pertinent cost the management must be able to ascertain what volume of sales can be expected at full cost. If a calculation of full costs is based on cost data for the past and, for example, it seems to require a sharp increase in price, the resulting fall in quantity sold may lead to a loss of scale economies, and the alleged full-cost price will in fact fail to produce revenues equal to costs as it is intended to do (NTIA, 1981: 67).

Braunstein also suggests that there may be an inconsistency between the objectives of OMB Circular A-76, which is intended to prevent Government entry into enterprises that can be better conducted by the private sector, and OMB Circular A-25, which requires full-cost recovery and thus encourages the Government to provide self-supporting services. As he observes with respect to A-25:

> This guidance conflicts with the basic premises that the government should run primarily by appropriated funds, and that if an activity can be self-sustaining, it should be conducted in the private, rather than the public sector (NTIA, 1981: 68).

Public/Private Sector Conflicts in Perspective

Discussions of such issues as full-cost recovery, which concern the relationships between the roles of the public and private sectors, are among the thorniest problems in scientific and technical information policy. Underlying these discussions are basic philosophical differences concerning the proper role of the Federal Government in providing information services products, and resources.

Those who favor restricting the role of Government and relying more on market forces place a high value on the American tradition of competitive private enterprise, and feel that the private sector can distribute information (originating from both Government and non-Government sources) most economically and most widely. They believe that the presence of Government "can have a chilling effect on private sector investment," and can reduce the efficiency of the marketplace in allocating resources (National Commission on Libraries and Information Science, 1982: viii).

Those who would prefer not to restrict the role of Government emphasize different sets of values, including the need for "equitable, open access...to information which has been generated, collected, processed, and/or distributed with taxpayer funds," and the importance of that information in ensuring broad public participation in the affairs of society, regardless of individual ability to pay. They stress that it is a proper Government role to meet those information needs not served by the marketplace and to stimulate "the development of information as a resource for dealing with societal problems" (National Commission on Libraries and Information Science, 1982: ix).

The most productive course of action lies not in attempting to decide which of the opposing views is correct in any absolute sense, but rather in seeking a middle ground that makes the best use of both Government and private sector capabilities to serve the Nation's scientific and technical information needs. This means determining the conditions and circumstances under which each sector is most capable, and establishing policies based on these determinations.

In part, these dilemmas in public-private relationships seem to have been brought on by the very success of Government scientific and technical information programs. Few concerns about unfair competition from Government were raised in the early days of programs like NTIS and MEDLARS, chiefly because start-up costs for such programs were high and the markets for their services were not large enough to interest many private firms. The Federal programs, taking advantage of advancing technology, helped expand and cultivate the markets, making them much more attractive today (Williams, quoted in Schuman, 1982: 1064). Now the market is more mature and the technology is less costly, thus the field is much easier to enter. The current need is to adjust to the new situation in a manner that best serves the public interest.

While there are no simple ways to accomplish this, some potentially productive approaches have been suggested in recent years. The common theme of these approaches is differentiating among types of information and their uses and allocating public and private roles differently in each case. One approach—that of Giuliano, et al.—described three basic modes of scientific and technical information transfer (termed "eras"), each corresponding to a different value system. Giuliano showed how different uses and expectations in each era affect the ways in which scientific and technical information is managed and distributed. Traditions and institutional mechanisms in the scientific and technical information field developed in connection with a transfer system in which the worth of information is seldom measured in economic terms. A variety of problems—including conflicts between public sector and private sector roles—result from the misapplication of systems developed under one set of values to situations in which different values are prevalent (Giuliano, 1978: 2-11).

A related approach was taken by a National Commission on Libraries and Information Science Task Force on Public Sector/Private Sector Interaction in Providing Information Services, charged with recommending means to resolve conflicts between the sectors. The task force developed a "schematic of contexts," which includes such factors as the social value of the information, its economic utility, the immediacy of its value, the ability of users to pay, etc., in order to help understand how conflicts concerning the appropriate role of the Federal Government in providing information services occur and how they might be resolved.

F. W. Horton, in an unpublished discussion paper circulated in conjunction with the Information Industry Association's new handbook, *Understanding U.S. Information Policy*, proposes a "hierarchy of needs" that information is expected to serve and suggests that pricing policies (and presumably public and private sector roles) be developed on the basis of it. The hierarchy begins with "coping information" and goes through "helping," "enlightening," and "enriching," to "edifying" information. In this scheme, "coping information" would be disseminated free of charge (presumably by the Government) while "edifying information" would be priced at fully competitive marketplace levels. Other categories would fall in between.

None of the approaches described here provides a definitive answer to this complex set of problems, but together they highlight the need to develop new ways to resolve the public/private sector controversies in information policy generally and in scientific and technical information in particular.

Access to Scientific and Technical Information

The growing commerce in information, prompted by the recognition of its value (social, political, and economic), has raised a number of concerns related to control of and access to information. The matter of access has special implications for scientific and technical information, since much of it is the product of a substantial Federal investment in research and development. Problems arise because of the often-conflicting Federal goals of providing information resulting from Government-sponsored research to the public, protecting the rights of individuals to privacy and of firms to confidentiality, assuring the Government access to information it requires for making regulatory and other decisions, safeguarding national security, and promoting domestic and international trade.

National Security

During World War II, a number of controls were placed on dissemination of scientific information for reasons of national security. These controls conflicted with the traditional scientific emphasis on open communication and the free flow of information.* The traditional position was stated in 1945 in *Science, The Endless Frontier*, a report prepared and submitted to President Truman by a task force headed by Vannevar Bush:

> Basically there is no reason to believe that scientists of other countries will not in time re discover everything we now know. A sounder foundation for our national security rests in a broad dissemination of scientific knowledge upon which further advances can be more readily made than in a policy of restrictions which would impede our further advances in the hope that our potential enemies will not catch up with us. (Bush, 1945: 29)

Balanced against the desire for scientific freedom and the need for Government accountability, which generally favors open access to information, has been the need to protect national security. Controls have taken such forms as increased classification of scientific and technical information and application of export regulations, and have placed particular emphasis on restricting the acquisition by the Soviet Union of American technology and scientific and technical information with potential military value.

The security classification system has evolved through a series of Executive orders. Since 1953, each successive Executive order has narrowed the definition of what the Government could classify. However, the most recent one, Executive Order 12356, issued by President Reagan in April 1982, reversed this trend by expanding the categories of classifiable information and revising various classification procedures. The new Executive order excludes classification of basic scientific research information not clearly tied to national security. However, distinctions between basic and applied research are blurring in many fields, and the implications of the order in certain sensitive areas, such as cryptography, are not yet clear.

*Free flow is used here to mean the "unrestricted" flow of information, rather than "no-cost" transfer.

The concern about foreign access to U.S. scientific and technical information has also been addressed through the mechanism of export regulations, including the Export Administration Act (50 U.S.C. App. 2401-2413) and the Arms Export Control Act (22 U.S.C. 2751-2794). These statutes impose licensing requirements on the export of certain goods, technology, and defense articles from the United States, and also restrict the access of foreign nationals to such material in the United States. Both statutes are defined broadly enough to include technical information and documentation as well as goods and services (Congressional Research Service, 1982; Relyea: 7). The International Traffic in Arms Regulations (ITAR) (22 C.F.R. 121.01 et seq., 1981), authorized by the Arms Export Control Act, require Government approval for publication of technical data with potential military significance. These regulations have been applied to embargo the export of advanced technologies, including computers, to the Soviet Union to protest its involvement in Afghanistan, and to restrict the dissemination of information at scientific and technical meetings.

Enforcement of these regulations (primarily by the Departments of Commerce and Defense) has been increasing under the Reagan Administration, causing some concern among many scientists unused to considering the implications of their work in terms of national security issues. Questions about the appropriate use of Government controls will continue to gain currency; the Export Administration Act expires at the end of September 1983.

One recent action reflecting in part the Administration's concern about the use of U.S. information processing and telecommunications systems—and scientific and technical information in general—by foreign nations was the withdrawal of U.S. Government support for the International Institute for Applied Systems Analysis (IIASA). Among the reasons for the decision was the Administration's desire to prevent Communist bloc researchers from obtaining unauthorized access to Western databases through IIASA computers (Walsh, 1982: 35).

Other laws intended to promote national security through control of information include the Atomic Energy Act (68 Stat. 919; 42 U.S.C. 2011-2296), which contains the "born classified" concept with respect to atomic energy restricted data, and the Invention Secrecy Act (35 U.S.C. 181-188), which provides authority for withholding patents containing sensitive information in order to keep the inventions in question secret.

A somewhat different means of controlling dissemination of information for reasons of national security is evolving with the development of a system of voluntary prepublication review of manuscripts on cryptographic research. The system is an attempt to balance scientific and commercial interests in the cryptographic and cryptoanalytic fields with concerns about the vulnerability of U.S. cryptographic systems. The extension of this policy to other areas of scientific research was proposed by former deputy Central Intelligence Agency director Bobby R. Inman at the 1982 annual meeting of the American Association for the Advancement of Science (AAAS). Inman suggested that "a potential balance between national security and science may be in an arrangement to include in the peer review process (prior to the start of research and prior to publication) the question of potential harm to the nation." If such voluntary security safeguards are not adopted, Inman warned, public outrage over the resulting "hemorrhage of the nation's technologies" would result in laws to restrict publication of scientific work considered sensitive on national security grounds.*

Discussion of the conflicts between secrecy based on national security and the unimpeded flow of scientific and technical information is under way in many forums and is the topic for another paper in this compendium. *Scientific Communication and National Security*, a recent report by a panel of the National Academy of Sciences, on the whole echoes the sentiments expressed in the Bush report, while facing realistically the need to restrict illegal acquisition of technology by other nations (National Academy of Sciences, 1982). The panel concluded that in by far the largest share of university research, "the benefits of total openness overshadow [the] possible near-term military benefits to the Soviet Union." At the same time, it noted that there are certain areas of research that should clearly be classified. It devoted special attention to the small "gray area" between the two, for which it felt "limited restrictions short of classification are appropriate." In this gray area, the panel suggested several specific means of limiting unauthorized foreign access to potentially sensitive research—means that it regards as consistent with the values of open science. It emphasized the need for the Government to define in concrete terms the areas in which the International Traffic in Arms Regulations and the Export Administration Regulations are applicable and indicated that these regulations should not be invoked to deal with gray areas in Government-funded university research.

Other International Issues

The international context for information policy includes many issues beyond national security concerns. The global flow of information has become increasingly possible as a result of rapid advances in data processing and computer systems and in telecommunications networks. The merging of these technologies has facilitated international commerce in information, including scientific and technical information, and has raised a range of associated economic, political, and technological concerns.

Responsibility for international information policy in the United States, like domestic information policy, has traditionally been dispersed among many parts of the Government, including the Departments of State, Commerce, and Defense, the Federal Communications Commission, and the Office of the U.S. Trade Representative. This division of authority contrasts sharply with the increasing efforts of other countries to develop and implement uniform national policies to regulate information and communication technologies and the form and content of transborder data flows. This is not to imply that the United States should necessarily emulate the approaches of other nations in information policy. Indeed, there are many good reasons not to do so. What is important is gaining an appreciation of

*For Inman's remarks and the response of AAAS executive officer William D. Carey, see *Aviation Week and Space Technology*, February 8, 1982, pp. 10-11, ff.

the strengths and motivations behind these approaches to information policy so that U.S. policy can deal more effectively with them.

National information policies are usually designed to build a nation's information independence and increase economic gains by developing indigenous information industries. While the desire to protect the privacy of individuals and to promote data security led to some of the early efforts by Europeans to control the flow of data, today a wide array of cultural, political, and economic motivations are behind such moves. Sweden enacted the first national data protection legislation in 1973; other countries, including Canada, France, and Germany, have since enacted information privacy or data protection legislation as part of their national information policies. The laws and enforcement provisions vary, but in most cases registration, public disclosure, and licensing restrictions are detailed. These regulatory efforts frequently form impediments to the free flow of information.

In October 1980, the Organization for Economic Cooperation and Development (OECD) adopted voluntary "Guidelines on Privacy Protection and Transborder Data Flows." About the same time, the 21-member Council of Europe issued its "Convention for the Protection of Individuals with Regard to Automatic Processing of Personal Data." Both codes govern transborder flows of personal data; the extent to which the transmission of corporate data is affected is often unclear.

Some restrictions, including the imposition of taxes, tariffs, and user fees, constitute economic barriers that may effectively price some providers of scientific and technical information services and equipment out of international markets. Such economic barriers are of particular concern to the United States, which has achieved a competitive edge in international markets for communications and information services (Congressional Research Service/Bortnick: 3; National Commission on Libraries and Information Science 1982: 27). Other regulations that restrict the flow of information between countries include requiring "domestic" information to be processed within the originating country (e.g., West Germany); requiring the purchase of host countries' equipment (e.g., Brazil); or, in some cases, complete denial of market entry (e.g., Canada, Great Britain) (Spero, 1982: 143; U.S. House of Representatives, Government Operations Committee, 1980: 18).

Potential requirements that data transmissions be monitored to ensure compliance with privacy regulations are also of concern. Business and governments are wary of the security of confidential and proprietary data when it is open to examination by other governments or when it is transmitted over public data networks (U.S. House of Representatives, Government Operations Committee, 1980: 16). Closely tied to this are the questions of national sovereignty and national security. Many nations feel threatened by the loss of control over databases that are stored and processed in foreign computer systems—especially in U.S. systems—subject to foreign laws (Congressional Research Service, 1982, Bortnick: 3). They are concerned about the ability to access their own data and the ability of other nations to access critical information when it is removed from local facilities.

Apart from the question of legal jurisdiction, many nations are concerned about such things as sabotage, equipment failures, and political decisions that might inhibit their ability to access their own data. They contend that once critical information is removed from local facilities, their vulnerability is increased as foreign nations and multinational corporations have greater potential to access it.

There is an additional concern that transborder data flows can lead to "cultural erosion." Although the United States maintains fundamental beliefs in the value of cultural diversity, other nations fear that the influence of the United States and other Western nations may disrupt their indigenous cultural heritage. These nations contend that foreign databases, as well as mass media, contain cultural biases that are potentially harmful to their societies. Although this perspective has been voiced by some Western nations, specifically Canada and France, it is of particular concern to developing countries, many of which lack a highly educated population and are consciously seeking to encourage adherence to traditional mores.

Indeed, the importance of access to foreign scientific and technical information for purposes of development and modernization versus the perceived economic and political vulnerability caused by reliance on foreign facilities and information is a particular problem for developing nations (U.S. House of Representatives, Government Operations Committee, 1980: 21). Databases and advanced information systems are often viewed with ambivalence by developing countries faced with the dilemma of assuring national sovereignty while requiring information p[illegible] and technologies for development (B[illegible] 1981: 32).

One illustration of this is the conflict over collection of agricultural, environmental, and geological data by remote sensing satellite systems such as Landsat. Nations collecting this data benefit from research applications and trade and investment opportunities; developing countries benefit from applications of the data to problems in such areas as agricultural productivity and natural resources management. However, some developing nations have tried to claim this information as a national resource, and sought to tax and limit its collection so as to prevent what they feel is exploitation by more advanced nations (Congressional Research Service, 1981: 61).

Protection of Domestic Proprietary Information

Among access issues on the domestic front in scientific and technical information is the problem of protecting proprietary information. Such protection is a central [illegible] commercial enterprises and ot[illegible] with claims of the "right" of [illegible] information. Patents and trade secrecy are the two most common means of protecting the ownership of commercial information while promoting its creation and application. Patent laws attempt to encourage communication by requiring disclosure of information about inventions in return for a 17 year legal monopoly. Trade secrecy law, on the other hand, allows employers to enforce nondisclosure clauses in contracts with employees or licensees to protect specialized knowledge that gives a firm some competitive advantage.

Questions of ownership and control of information are increasingly complex, particularly in high-technology fields such as microelectronics and biotechnology, where the lines between basic and applied research are narrowing. For example, patent prospects may affect release of data and inhibit communication among scientists who have a vested interest in research results (Nelkin, 1982: 706). Findings that may be important to the advance of basic research may be withheld from publication because of commercial interests in potential applications.

The notion of scientific ideas and data as intellectual property, and the related question of ownership of intellectual property, are both critical to scientific and technical information policy. While precise definitions of intellectual property vary, it is generally assumed that investigators have the right "to enjoy the fruit of their intellectual labor" (National Telecommunications and Information Administration, 1981: 76). This right is protected in varying degrees by patent, trade secrecy, and copyright law. The copyright laws protect individual or group rights to unpublished and published works for a specific period of time and permit compensation to the copyright holder for use of the materials.

Government support for R&D leads to questions about ownership and disclosure of data produced in non-Government institutions under Federal funding. Grant provisions favor public disclosure of research results, but those guidelines are considered subject to the researcher's right to decide when results are ready to be published (Nelkin, 1981: 704). Funding agencies may request access to data to verify the progress of research; this information may, in turn, be subject to disclosure upon request under the Freedom of Information Act or other regulations (Gordon, 1982: 10). These are but a few of the problems of safeguarding the disclosure of personal and proprietary information that has been provided to the Government.

Scientific and Technical Information and Federal R&D Policy

The preceding sections of this paper have outlined a number of issues involving scientific and technical information currently facing policymakers and the scientific and engineering communities. Several factors are combining to give these issues a special urgency.

The division of labor between the public and private sectors in the provision of scientific and technical information services has been under discussion for several years. Its salience has increased considerably, however, during the recent past, as the Reagan Administration has sought to reduce the role of the Federal Government in society and to transfer to the private sector those functions that it believes can be performed more efficiently and effectively outside of Government. At the same time as this redefinition of Federal roles and responsibilities has been taking place, awareness of the importance of R&D and technologically based industry in economic recovery and in the solution of social and national security problems has been growing.

In this context, there has been some discussion of shifting responsibility for functions served by Federal scientific and technical information systems such as NTIS and NLM to the private sector. In general, these discussions have come up on a case-by-case basis and have not been related to a systematic examination of Federal scientific and technical information policy. Further, they have given little consideration to possible long-term consequences to the U.S. R&D system of limiting access of U.S. users to scientific and technical information and possibly allowing foreign control of U.S. scientific and technical information resources.

Issues of access to scientific and technical information have come to the fore mainly in terms of growing emphasis on national security concerns and increased recognition of the importance of science-based technology to U.S. security—both military and economic. Although studies such as that conducted by the National Academy of Sciences have helped to focus the arguments in this area, the need to address national security concerns may drive policy in a manner not well linked to broader questions of scientific and technical information policy (National Academy of Sciences, 1982).

Finally, the technology of information itself is advancing rapidly and offering both problems and opportunities for the U.S. research system. The most recent *Five-Year Outlook on Science and Technology* suggests the potential importance to scientific and technical communication of such developments as electronic "mail" (for rapid exchange of scientific data), the growing capabilities of electronic data bases, and new, electronic forms of rapid publication (National Science Foundation, 1983). The continued development and implementation of such technologies, although likely to be based in the private sector, depends in part on the Federal role—both directly through Federal support for the development of associated technologies, and indirectly through incentives and disincentives to the use of such systems built into Federal R&D policies.

In these and other policy issues affecting scientific and technical information, the Federal Government plays many different roles, including:

- *Generator of scientific and technical information*, through federally funded R&D efforts;
- *Provider/disseminator of scientific and technical information*, through Federal information centers and data bases;
- *User of scientific and technical information*, in its performance of R&D and in other technologically based activities, such as regulation;
- *International negotiator*, i.e., representative of U.S. interests in various international forums;
- *Mediator of competing interests*;
- *Policymaker*, a locus of decision for controversial issues and authoritative allocator of public resources; and
- *Source of technical advance*, through support of R&D in communications and information technology.

The Federal role is not exclusive in any of these areas. Commercial enterprises—as R&D performers, as sources of information technology, and as providers and users of scientific and technical information services—are involved throughout, as are universities, nonprofit organizations, and professional scientific and engineering associations. Nonetheless, Government involvement is pervasive and inescapable as part of the recognized Federal responsibility in the support of R&D and application of its products to the Government's and other national needs. This pervasiveness means that Federal policy for scientific and technical information *will* be made and will have an important influence on the course of events in this area. The choice is between allowing that policy to be shaped by unintended consequences of choices made in other domains, making it the net result of numerous uncoordinated efforts, or, alternatively, having a policy developed on the basis of conscious, purposeful decisions, based on data and understanding of the issues and structured to lead to a desired outcome. The importance of scientific and technical information to the R&D enterprise dictates that it be the latter.

Policy Options

To address the issues outlined above will require a concerted effort on the part of policymakers in the Federal Government and among the numerous other stakeholders whose interests are associated with the area of scientific and technical information policy. Making the importance of the issues in this area better known and gaining the attention of individuals in organizations whose interests are involved is an important first step to which this and similar papers may contribute. Beyond this, it may be useful to suggest a number of specific options for further examination and action:

(1) *Reexamine pricing policies for Federal information services.* Many of the conflicts between the public sector and the private sector in scientific and technical information policy center on the prices charged users by Federal information services. Although there are a variety of high-level policy statements on the subject, agency policies differ considerably and both the information services and their users could benefit from an overall systematic examination of pricing. The values of implicit and explicit subsidies to users should be included in the examination, as should alternative means of providing those subsidies. The concepts of differential pricing discussed above under the heading "public/private sector conflicts in perspective" merit consideration in this context.

(2) *Make representation of U.S. interests in scientific and technical information a conscious element of foreign policy.* Actions of foreign governments in the information field may in some cases have significant negative impacts on the U.S. R&D community and on U.S. scientific and technical information services, in both the public and the private sectors. Traditions and circumstances in the information field in the United States are different from those in other countries, and this country should not necessarily emulate the actions of others. It is essential, however, that U.S. foreign policymakers recognize the importance of U.S. scientific and technical information interests and actively represent them. The flow of scientific and technical information is included among these interests, both as an element of foreign trade and as an intellectual resource for the U.S. research and industrial communities.

(3) *Examine the policy structure for scientific and technical information in order to define more clearly authority and responsibility.* Too often problems in scientific and technical information seem to "fall through the cracks" because organizations capable of dealing with them do not exist at the proper hierarchical level or because high level policymaking bodies have too many competing interests to devote adequate attention to them. Creation of a new "Office of Information Policy," as has been proposed from time to time is not likely to be the answer. But a systematic review of the adequacy of existing organizational arrangements and a possible reassignment of responsibilities seem both appropriate and timely.

(4) *Enhance awareness of scientific and technical information issues among R&D policymakers.* Of the several contexts in which decisions on scientific and technical information issues should be considered, that of R&D policy is particularly important. Yet decisions on scientific and technical information issues seem all too often to be made independently of R&D policy decisions. R&D policymakers should be encouraged to recognize and pursue their interests in scientific and technical information issues.

(5) *Provide a forum for continuing discussions among parties with different viewpoints and interests in scientific and technical information policy.* Apart from the other suggestions contained here, it would appear

that if real progress is to made in resolving the issues of scientific and technical information policy, many organizations and individuals with widely differing viewpoints will need to subordinate conflicting interests and act on the basis of larger common interest. An important step in this direction would be the establishment of a setting for initiating and maintaining discussions among these parties and a mechanism for assuring that the policy process is informed by the results of these discussions.

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that if real progress is to made in resolving the issues of scientific and technical information policy, many organizations and individuals with widely differing viewpoints will need to subordinate conflicting interests and act on the basis of larger common interest. An important step in this direction would be the establishment of a setting for initiating and maintaining discussions among these parties and a mechanism for assuring that the policy process is informed by the results of these discussions.

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FCC felt the Act mandated it to protect existing service, which by definition (since the FCC was on the job) served the public interest. This often meant a cautious and even negative attitude toward any technical innovations that might threaten the financial health of current broadcasters. Services that could have provided additional outlets for television, causing no interference and ameliorating scarcity to some degree, were hampered by regulatory restrictions. The regulatory environment in turn dampened investment and innovation. The FCC's plan for allocation of Very High Frequency (VHF) and Ultrahigh Frequency (UHF) channels to television stations wound up discouraging the formation of more than three national networks. Severe restrictions on the broadcast signals that cable systems could carry and on the markets they could serve, strict and expensive specifications for satellite receiving stations, and limitations on pay television held back the growth of cable (17; see also 4; and 18: 11-16).

These regulations may have protected the profits and services of existing broadcasters. But, by the 1970s, it had become increasingly clear that technology was leaping beyond the old assumptions. Scarcity did not seem inevitable. New outlets for video telecommunications were making it possible to envision a genuine competitive video marketplace to replace Government-regulated scarcity. Influential scholarly and political analyses of the banes of overregulation began appearing (29; 31), reinforcing the perception that a market approach was both feasible and preferable. Deregulation in such areas as trucking and airline travel enhanced its acceptability among communications policymakers.

Prompted by these developments, the FCC began to question the assumptions and loosen the bonds. The process of deregulation continues. Precisely where it should apply, and where regulation should be enforced or modified, is the major question this paper addresses.

The Geostationary Satellite and the New Abundance. Although it is impossible to identify all the technical developments that undermined the persuasiveness of the scarcity assumption, probably the most significant was the proliferation of geostationary earth satellites. Perched 22,300 miles above the Equator, these small machines receive signals transmitted from earth stations and retransmit them to parabolic dish antennas located across wide regions (a time zone or two) (see 33 for a description of satellite technology). They are now relatively inexpensive to build, launch, and operate (26: 219-23). As more were put into orbit, more channels became available at progressively lower cost. This allowed television networking at a price significantly lower than that of the previously used land relays. Home Box Office (HBO), now the largest pay cable service with 9 million subscribers (7), was the first to utilize the potential. It began feeding movies to cable systems via satellite. At first, HBO was hampered by FCC regulations. When the Commission dropped some restrictions, HBO took off, to be joined by dozens more satellite networks.

It is difficult to overstate the magnitude of change: the United States went from four television networks in 1977 to some 50 in just 5 years. Perhaps 15 of these reach significant numbers of subscribers. With few exceptions, the cable networks currently reach much smaller audiences than the TV networks; many of the cable networks will not survive the decade. Indeed, the premier cultural network, CBS Cable, shut down in December 1982. Still, the new networks are profoundly changing video telecommunications. Simultaneously, cable and other new delivery systems are creating capabilities besides mere relaying of entertainment.

The Current Market and the New Competitors

Broadcast Television. The core of video media remains the three commercial broadcast networks and their affiliates. There are about 610 stations associated with the three commercial networks, some 260 public television licensees, and 155 independent commercial stations. The industry had more than $8 billion in revenue in 1979, over half of which went to the three networks and the five VHF stations that each owns and operates (40: 283). Over-the-air television continues to garner by far the most viewers and revenues. But its audience share is declining as the newer services expand.

Cable Television. As of 1981, there were some 4,350 cable systems with total revenues exceeding $1.7 billion (only about one-fifth of broadcast television's) (40: 291). Cable began as a rural service providing clear television signals to townsfolk beyond the reach of big-city broadcasters. As late as 1969, there were only 3.1 million subscribers. By October 1982, basic cable subscription had risen to 27 million—about one in three of households with television. Pay cable services (premium programming such as that offered by HBO for an extra monthly fee) are taken by nearly one in five TV households (7). These figures should continue to grow rapidly, especially since most of the Nation's largest cities are still in the process of being wired and several (Detroit, Baltimore, Washington, Chicago, and New York's four outer boroughs) have barely begun.

Cable service is organized into "basic" and "pay" services. Basic includes broadcast stations; automated services providing readouts of time, stock quotes, headlines, and weather; channels for locally originated shows; and a choice among some three dozen satellite networks. The networks earn revenues from advertisers and some charge cable operators small fees (1-20¢/subscriber/month). Among these are one "cultural" service, two aimed at women, one specializing in black affairs and culture, two headline news services and two more in-depth public affairs channels, two emphasizing sports, one for children, and another for teenage music afficionados. Basic service averaged about $7.69 per month in 1980 (14: 1). About a dozen pay services, which are provided for additional monthly fees averaging $8.73 per month (14: 1), emphasize fairly recent movies, Broadway shows, and Las Vegas-type entertainment shown without commercials.

The older cable systems—still one-half or more of the total—only offer 12 or fewer channels. Advances in cable technology now make it possible to provide 54 channels on a single cable, and systems using dual cable offer up to 108.

Besides entertainment and news, these newest systems promise to offer an array of services that bring the widely heralded information age to fruition. The basic technical innovation is the microprocessor. The silicon chip enables the cable to go two-way—essentially installing small computers at the subscriber's end and a larger computer at the system end. Central computers might be linked in turn to computers run by banks, newspapers and other data bases, merchandisers, and security alarm services. Shopping and banking at home, electronic newspapers, interactive information retrieval, and home and business security are provided on some cable systems. In addition, cable can be used to hook up institutions and businesses for high-speed, high-volume data transmission as well as teleconferencing. Such a network has existed in Manhattan for 8 years. All of this can be done much less expensively than by telephone because of the larger frequency capacity of coaxial cable compared to traditional uses of the twisted pair of copper telephone wires. Half-inch coaxial cable can handle as much information as 30,000 twisted pairs (26: 327-37).

All the channels cable offers may be supplemented by several other infant or about-to-be-launched services.

Subscription Television. In recent years, the FCC also relaxed its restrictions on subscription television (STV), which broadcasts a scrambled signal over one channel and rents the descrambler for $20-25 per month. The fare is similar to that of pay cable. As of September 1981, there were estimated to be 1.4 million subscribers (41). The future of STV is problematic. Where cable is available, consumers can purchase basic cable service and one or two pay channels for the price of one STV channel.

Multipoint Distribution Service. Multipoint Distribution Service (MDS) uses an omnidirectional microwave transmission for one channel of commercial-free premium entertainment. Most MDS systems offer HBO or other cablelike services for about $20/month. There are 400,000 MDS subscribers currently, with a projection of 1.4 million by 1985 (40: 303). Although one-channel service would appear little competition to cable, the FCC has authorized five-channel MDS. If five channels with high-grade offerings were priced below or with cable, MDS could prove a vigorous competitor.

Direct Broadcast Satellite. The FCC has authorized a new service that will employ satellites broadcasting directly to homes equipped with small (under 1 meter) receiving dishes. The equipment will cost $200-500, with a monthly charge of $20 for three or four channels. The nascent industry is explicitly targeting those homes likely to be beyond the reach of cable (19). The Direct Broadcast Satellite (DBS) service should begin by 1984.

Low-Power Television. The FCC has also authorized a low-power television station service (LPTV) and is currently processing several thousand applications. Though using a fraction of the power of full service stations (thus avoiding interference) the typical LPTV operation could cover a radius of 12-15 miles—enough to serve Washington, D.C., and many of its closer suburbs. Equipment start-up costs are as low as $100,000 (16: 80; 25).

The authorization of LPTV illustrates changes in Commission thinking that are helping to stimulate abundance. The FCC staff report recommends that "consumers should be able to take full advantage of the technologies available in the marketplace under the presumption that competition will best serve the interests of the public" (16: 182). Far from regarding competition as a threat to the public interest, the FCC staff report holds it to be the best way to achieve the public interest.

In accepting these recommendations, the Commission was influenced by technological changes. The cost of production equipment has decreased significantly, due in part to the drop in the price of microprocessors. Those components have also increased equipment reliability and diminished the danger of interference. Simultaneously, the new availability of inexpensive satellite channels and earth stations enhances the possibility of forming national networks of the low-power stations (25: 39-58).

A Note on Telephone and Other Media. Space limitations preclude consideration of equally epochal alterations of the telephone, computer, and radio branches of telecommunications; also omitted are videodiscs and videocassettes. Lines between the technologies grow less and less distinct, however, and developments in these areas will ultimately affect television and cable.

The telephone industry will alter in especially dramatic fashion as a result of recent antitrust rulings. AT&T will no longer provide local phone service. It will instead expand from long distance service and equipment provision into information and computing services. In all these markets, AT&T will face increasing competition. The company is not likely to become active in the video field in the near future, except perhaps in delivering data to be displayed on TV screens (teletext or videotext). In the longer term, AT&T and its telephone competitors may well nurture new technologies that compete more directly with cable and broadcast video, but these are not predictable now.

Emerging Policy Issues and Options

The rise of the competitive video systems is the major fact of life for the three commercial networks and for public television. Growing competition is the driving force behind virtually all of the legal and regulatory issues and initiatives that pervade broadcasting (see 28). Only cable and broadcasting now pose significant competitive threats to each other, but all the alternatives figure in current policy debates and industry planning. Underlying most policy issues in both cable and broadcasting, in fact, is one central question: Just how vibrant is the competition between them? For representatives of each industry, the strength of the other provides the sustaining theme to calls for deregulation. With cable systems offering dozens of outlets, broadcasters say channels are no longer scarce, removing the need for regulations based on scarcity. For cable operators, the continuing popularity (and wealth) of broadcast networks provides a competitive check preventing abuses of the cable system's local monopoly.

The transition from a regulated and relatively uncompetitive video market with a handful of channels to competition and abundance is raising four interrelated sets of issues:

- How should *participation* in the video marketplace be regulated? This issue includes Government licensing and franchising and technical standard-setting.
- How should the video *content*—the entertainment and information messages themselves—be regulated? This issue includes questions about ensuring balance and diversity in broadcasting and cablecasting.
- What policies will best ensure that a *truly competitive video market* emerges and persists? This problem encompasses regulating cross-ownership and joint ventures among media corporations and ensuring programmers' access to new outlets.
- What *dangers* to democratic rights and assumptions are posed by the telecommunications revolution? The two matters of greatest significance here are the protection of privacy and the possibility of an information gap opening up between rich and poor.

These will be the subjects of the remainder of this paper.

Participation in the Video Marketplace

The arguments for deregulation of entry and exit—for extending license or franchise terms indefinitely—are based largely on the increasing competition between broadcast and cable television. Limited license and franchise terms were designed to subject performance to evaluation every few years. Some argue the effect has instead been to discourage efficient investment.

Television License Terms. Although, in practice, television licenses are virtually never revoked, the need to face the Commission triennially was felt by some to have induced more cooperation with viewer groups and thus better service. Now, the deregulation advocates argue, competition from other video providers creates an incentive for high-quality performance by licensees. Besides, they say, since the Commission hardly ever revokes, renewal paperwork reduces to little more than an expensive ritual. Apparently buying that argument, Congress extended television license terms to 5 years in 1981, and the FCC Chairman appears amenable to extensions that would essentially create a private property right in licenses. Government renewal would not be necessary and current restrictions on buying and selling station licenses would be lifted. Market entry and exit would be left to the market.

Cable Licenses Are Local Franchise Agreements. Regulation of participation in the cable market has been quite different. With few exceptions, most of the regulation is performed by State and local governments. The FCC has discontinued most of its cable regulations. Municipalities negotiate 15-20 year franchise agreements with cable companies, which they (sometimes with a State agency) oversee and enforce. Not surprisingly, the industry confronts a set of demands and strictures that varies widely from locale to locale. Citing the competition they face from broadcasters and other technologies, deregulation advocates have requested national legislation to codify and limit the jurisdiction of local governments.

Such a bill, S.2172, passed the Senate Commerce Committee in July 1982. A similar bill, S.66, was passed by the Senate in 1983. Perhaps the most controversial provision is the requirement that cities renew the franchise agreement upon showing of reasonable compliance with its provisions. Fractious renewal negotiations have alarmed the industry. Industry members feel small towns and cities with older systems are making unreasonable demands at renewal time for totally new 108-channel state-of-the-art systems. They feel these are not good investments outside densely populated metropolises (and perhaps not even there). Broadcasters, MDS, STV, DBS, and the rest face no such close controls on investment. The Senate bill, they claim, will allow all the video providers to "compete on a level playing field." The legislation would, in essence, give cable operators indefinite local licenses of the sort television stations are also seeking.

City governments, with experience in negotiating and administering franchise agreements, point to studies showing virtually no franchise renewals denied. Like the advocates of continued FCC broadcast licensing, they argue nonetheless that the renewal processes keep the companies honest in a way the marketplace simply cannot (see 39). The National Cable Television Association (NCTA) will certainly continue to seek deregulation.

Government Standards Versus Market Reliance. On FCC standards, Christopher Sterling has written, "For decades, the Commission's role was clearcut: industry developed potentially competitive standards for a given spectrum-using service and then, under FCC guidance, comparatively tested them. Based upon the results...the FCC would then decide which transmission standard best served the public interest...." (37: 138). Now, however, the introduction of competing new technologies has been so rapid "as to defy careful policy consideration." (37: 139). In addition, budget cuts at the FCC have severely limited its ability to engage in the complicated process of standard development. And, with proliferating market alternatives, many question the need for Government to make detailed proclamations as to what is in the public interest.

The FCC seems to be moving away from setting standards on the assumption that standards decrease the speed and raise the cost of establishing an innovation in the marketplace. The FCC's recent decision not to set a standard for stereo AM radio reflected, in part, this belief. Critics have argued that the effect could be just the opposite, however. Because of the inevitable period of competition among alternatives, all but one presumably becomes obsolete. That discourages investment. Opponents also assert that antitrust rulings limit the ability of private manufacturers to set their own standards, that large radio manufacturers and not individual consumers will make the ultimate selection, and that the period of competition will allow foreign manufacturers to gain a foothold (37).

Deregulation advocates counter that there is no clear evidence for any of these claims. In addition, in some uses setting standards would have negative effects on specific population groups. Existing low-power television standards, for example, could price LPTV stations beyond the reach of rural and urban minority audiences who are supposed to be prime beneficiaries of the service (37: 144). Finally, the inevitable problem with standards is that they may rigidly shut out future technical innovations. One suggestion has been to enforce a standard for a few years to allow the technology to take hold, and then "sunset" the rules. If any superior techniques arise, they are then allowed to participate and succeed or fail in marketplace competition against the old standard. The debate is likely to continue, with stereo television transmission standards looming as a major test of whether the Commission will bow to the pressures of those who want it to set standards to speed innovative market entry, or will stay the deregulatory course (36; see also 38 and 42: 83-86 on videotext standards). In either case, the relatively slow pace of FCC deliberation contrasts sharply with the hyperactivity of communications technology. The FCC will likely lag behind technological developments for some time to come—yet another argument for thoroughgoing deregulation.

Content Regulation

There can be no doubt that cable has greatly reduced scarcity of channels for its 27 million subscribers. But that fact in and of itself does not answer the concerns of those who favor continued "public interest" regulation of video content. Rising competition between cable and broadcast television does not guarantee accomplishment of the original goals of content regulation.

"Fairness" of Telecasting. Several rules designed to promote public enlightenment regulate the content of telecasts. Among these the most contested is probably the Fairness Doctrine (13). The doctrine stipulates that stations must devote time to controversial issues and must offer reasonable opportunity for the discussion of contrasting views on them. Many observers believe the effect of this rule is to *discourage* issue programming. Stations fear any controversial view they show will subject them to demands for time from opponents, or complaints to the FCC if they deny requests for access (30; 31). Public interest groups counter: If the FCC vigorously advocates of continued FCC broadcast licensing, they argue nonetheless that the renewal processes keep the companies honest in a way the marketplace simply cannot (see 39). The National Cable Television Association (NCTA) will certainly continue to seek deregulation.

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If, after a shakedown period, only a handful of basic, mass-targeted, ad-supported cable networks survive along with a few pay services, the market will be less abundant than promised. Serving narrower interest audiences, as cable was supposed to do, may simply turn out to be a bad investment. Kay Koplovitz, president of the ad-supported USA cable network, believes that "the economics are very tough for narrowcasting, and the narrower the programming the tougher it gets" (11: 60). A major economic study released in September 1982 predicted only 8-10 viable ad-supported cable networks by 1985 (22).

Beyond this question is the potential problem of channel scarcity. Several pay and basic networks started up in 1983, including a Disney channel and a country music service. A substantial proportion (upwards of 50 percent) of systems—those with 12 or fewer channels—will not have the capacity to carry them. Even some relatively new 36-channel systems are full.

Of course, more optimistic scenarios can be constructed. And the benefits of a half dozen or dozen new networks, even if mass-targeted, should not be gainsaid. The question remains whether the market as it is likely to emerge actually will serve the same ends as FCC regulation was designed to do. Will diverse views flower? Local programming? Political debate? What should be done if the market fails and if we remain skeptical about moving back toward a more heavily intrusive FCC (see 21)?

One option is to abandon the goals themselves as unrealistic. Another option is to rely upon the new videotext services, more attuned to information than entertainment, to multiply the access of citizens to wide-ranging information. The competitive response of the newspaper industry to videotext may enliven them both. Indeed a reasonable scenario may be substantial competition in video mass entertainment via broadcast, cable, and the technologies aborning; and competition in information provision via videotext, newspaper, magazines, and books. While less than the nirvana of competitive abundance some envision, this system would offer significantly more than the present regulated market.

Ownership Restrictions. In the late 1970s, the FCC appeared to be moving away from content regulation but toward stricter oversight of market structure, with a great concern to prevent anticompetitive combinations of media entities. By 1982 that tendency had all but disappeared. Deregulation in this area too is a clear goal of the Commission majority.

Current restrictions on ownership take several forms. Single entities are not allowed to own more than seven television stations (a maximum of five can be VHF) (47 C.F.R. 73.636(b)). Television stations cannot own cable systems or newspapers located in the same area (with some "grandfathered"-in exceptions); nor can the TV networks own cable companies, although this restriction is one of those in process of abolition (1: 35-36). The FCC places no limit on the number of cable systems a single entity can own and does not prohibit a cable company from common ownership with a newspaper. Proponents of further deregulation ask, precisely what harm would come of a free market in television stations and other media? Compared to many industries, television station and cable ownership are far from concentrated. Economies of scale might well improve the service offered by those independent TV stations and/or cable systems absorbed into large conglomerates (see 17).

On the other side stand those fearful of the concentration of political power that might accompany large-scale acquisition and merging. Those who favor continued FCC regulation also point to numerous potential abuses by cross-owned newspapers, television stations, and cable systems, whether in setting advertising rates or covering local issues and campaigns. These possibilities, they feel, are not necessarily susceptible to cure by competition from other media outlets. Regulation proponents further base their legal case on the "Associated Press principle" (326 U.S. 1 (1945))—that the underlying assumption of the First Amendment is that the American people will receive information from diverse and antagonistic sources.

Some complex interactions between efficient investment and innovation make choosing policy quite difficult. The established TV networks have all been moving vigorously into the new technologies. If, as some suggest, this entrance should be foreclosed, CBS, et al., might be doomed to stagnant profits at best, bankruptcy at worst. Keeping the networks out of cable, MDS, DBS, and the rest would prevent them from responding fully to the evolving market. On the other hand, by letting them into joint ventures in cable program production or direct ownership of cable systems, the Government risks anticompetitive behavior as well as violation of the "Associated Press principle."

Deregulation advocates appear confident that the burgeoning marketplace would indeed prevent transgressions, that the Antitrust Division of the Justice Department will be on guard, and that private antitrust suits will be effective enforcers of competition. In apparent agreement, the FCC has been moving quite forcefully toward deregulation of ownership restrictions. Congress has not yet spoken on the issue.

Access to Cable Systems. A representative fear of those who endorse continued ownership oversight is that local cable systems may become bottlenecks that block program and service providers who desire access to subscribers. The barriers may result from vertical integration, where one company has an interest both in the system and in program services. Such integration is common. American Television and Communications (ATC), the largest cable system operator, for example, is owned by the same corporate parent as Home Box Office: Time Inc. While HBO is offered on essentially every ATC system, its competitors are offered on only a few.

There are numerous tie-ins of this sort between program suppliers and cable systems. In addition, many cable program networks are joint ventures between two or more cable system operators. Such networks may gain easy access to their parent corporations' cable systems. With a continued shortage of open channels on most systems, cable programmers who are not related to cable operating corporations may be shut out.

One solution proposed for bottlenecks is mandatory leased access: setting aside a portion of each system's channels as open to the highest bidder. The cable industry strenuously opposes such ideas. With some reason, it fears enforcement of leasing requirements would lead to treatment of cable as a public utility, with all of its well-known inefficiencies. Other alternatives have been proposed (for example, separated subsidiaries or compulsory arbitration). Most believe that required leasing or other forms of access could be mandated only with close oversight of rates and leasing practices. The costs of such an apparatus may outweigh any benefits of unclogging the bottleneck (see 5). A preferable alternative may be reliance upon private antitrust suits, where courts can impose treble-damage settlements on anticompetitive firms.

Protecting the Rights of Individuals

In the glow of enthusiasm over the new age of multifaceted information, two central issues of individual rights will not be overlooked. The first is privacy; the second is a potential information gap.

Privacy and the Nature of Two-Way Cable. The privacy problem exists in direct proportion to the enormous potential of two-way interactive cable. Essentially unlimited amounts of information can be stored in computers and transmitted via cable. Videotext subscribers can send orders to the computer for specific items—from news reports to recipes to book chapters and much more (see 23). The same marriage of computer and two-way capability enables cable systems to conduct instant polls including the widely publicized "Qube" polls on some Warner-Amex systems; banking and shopping at home; and "pay-per-view" showings of first run movies and prize fights.

The computers for these interactive systems, then, will collect detailed information on program preferences, finances, shopping habits, and political opinions of subscribers. These data would be enormously valuable to merchandisers, political candidates, employers, credit raters, and, conceivably, public officials ferreting out dissidents. Cable operators will be under considerable economic or political pressure to sell or share these valuable data. Individual cable system employees may be subject to blandishments from those who want embarrassing information about a specific individual (perhaps a candidate). Legal action may be brought to bear by police forces or parties to lawsuits to force the release of data. As computer networks become increasingly intertwined and interdependent, the damage that mistakes or incomplete entries might do to an individual's credit rating or job prospects increases—as does the difficulty of discovering or erasing an error (see 42).

Government regulations already cover credit rating services, although they might not cover all the contingencies raised by the new technologies. Local cable franchise agreements often include provisions for privacy protection. Warner-Amex, the owner of Qube, has its own voluntary code of good practices. Local oversight and voluntary self-regulation may prove sufficient.

Yet one aspect of the dilemma is that violations of policy are difficult to detect. Computers will be exchanging information with each other and may not leave an easy trail for privacy guardians to follow. Another difficulty is that the conceptual line between legitimate uses of the data, say in assessing credit reliability, and forbidden uses may not be easy to draw.

Possible Ameliorating Factors. Videotext is in the earliest stages of development. It may never become widespread. To the degree it is not, privacy concerns recede. Currently, the cost is quite high—$10, for example, for a half-hour's use of the CompuServe data base (which includes the *Washington Post* and other newspapers) (8). In England, home use has fallen drastically short of projections (38).

A second force that may protect privacy [illegible] he same technology that threatens it. [illegible] criber signals could contain codes that [illegible] e their identity or cause automatic [illegible] from the central computer's memory. [illegible] rotections could be mandated by [illegible] enforced if built into the computer [illegible] and software. Then the issue will [illegible] political one: which data should [illegible] ected and which should be open [illegible] ercial exploitation? This is likely to be an issue for some time. In some ways the battle lines will resemble those between ecological conservationists and developers.

An Information Gap? A second policy concern is the possible development or widening of an information gap among the citizenry. If cable and network television offer more entertainment choices than ever before, and videotext and other forms of two-way cable remain expensive, two classes could arise. One group would be even more attracted to and dependent upon television entertainment than is already common. Another, much smaller segment would have an expanding world of information at its call. Only for a small group who could afford it would the competitive video marketplace be fully implemented. For the rest—those living in rural areas beyond the reach of cable, or families unable to commit $50 or more per month to video—there would perhaps be some more entertainment channels, but visions of an efflorescing world of competing ideas and alternatives would simply not pertain.

This seems an undesirable outcome, but policy solutions are elusive. "Electronic information stamps" or tax credits could be offered to the poorer classes in recognition of the inherent right (or democratic desirability) of all citizens to have equitable access to information. A universal service doctrine could be implemented in cable as it was for telephone service, where business and urban long distance (in other words, middle and upper class) users paid higher rates to keep rural and urban local calling inexpensive.

But even if such policies were implemented—and they would be costly—citizens could not be required to seek or use information (8). Nor could they be prevented from seeking gratification in entertainment. The information gap could arise whatever policies are attempted. Debate over this problem may come to replace the well-worn arguments over television's encouragement of violence and debasement of reading skills (see 12; 32).

Conclusions

The video telecommunications industry is in great flux. Technologies that seemed unmoving are now progressing rapidly. And assumptions and policies that once seemed sacrosanct are now vigorously debated—and altered. Indeed the regulation of telecommunications is now changing almost as rapidly as the technology of telecommunications.

Though by no means certain, the most likely legal and regulatory scenario for the rest of this decade is a shift in both the substantive focus and the locale of the video regulatory action. From a concern with licensing standards and regulation of content, the emphasis will move toward maintaining a competitive market structure—and deciding just how freely competitive the market should be. In particular, the policy debates and directives will be in the realm of antitrust. Telecommunications players will attempt to protect competitive positions, sometimes by limiting competition. And they will oppose as anticompetitive those actions and actors they perceive as threatening their growth. As a concomitant, the scenes of greatest regulatory activity will switch from the FCC to the Congress and courtrooms. The Commission will be relegated to increasingly technical (though hardly apolitical) matters of standard-setting.

On the question of regulation of entry and participation in the marketplace, it appears Government will remain involved but to a lesser degree. A cautious attitude toward new entrants will be replaced by a warmer welcome. Setting technical standards for entry may remain a major FCC function. But even here the Commission has recently evinced a distaste for intervention.

Debate about content regulation will center in the near term on the advisability of overseeing broadcast television. In the slightly longer run, it seems quite possible that most FCC content regulation of TV will be eliminated de facto if not de jure, and that few rules will be applied to cable and the emerging video media.

The matter of maintaining a competitive marketplace will probably become increasingly complicated; the hopes of free marketeers for wholly hands-off government notwithstanding. For many years, the established members of the telecommunications industry enjoyed a quiet, quasimonopolistic existence, where each respected the other's turf. Now, conflicts between telecommunications companies in the legislature and courtroom may grow more intense as potential competition and stakes in the market grow. For example, the NCTA recently announced that it may seek legislative protection from the entrance of AT&T into the video and videotext markets (27).

Individuals' rights to privacy and to information access will emerge as major concerns for some groups. This area may generate the most publicized controversy, the most philosophically puzzling implications, and the least definitive solutions. The FCC will have little role here; the Congress and courts will be the arbiters of any policy that emerges.

Government officials who make the final policy decisions will be weighing complex uncertainties and tradeoffs. If they choose wisely, the outcome should be a reshaped industry contributing substantially to a revivified American economy.

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Trends in Computers and Communication: The Office of the Future

Abstract

Office automation and communication technologies have just begun to penetrate the U.S. market. They promise dramatic gains in productivity in the service sector of the economy and equally dramatic gains in the productivity of individual firms and agencies. The promise of productivity gains from office automation comes at a time when the U.S. economy is shifting from a manufacturing to a service base and is experiencing an associated decline in productivity growth rate. Because the expected promise of the new office automation technology has not yet been realized, several issues confront policymakers in both public and private institutions. This paper describes the new technology and some of the reasons that have been offered for its unexpectedly slow acceptance in the marketplace, anticipates some of the implications the new technology has for the nature and organization of office work in the future, and offers some thoughts on the broader societal consequences of office automation. Different problems and policy issues arise, depending upon whether the new technology will be accepted rapidly or slowly. The paper identifies these problems and discusses actions that could be taken by industry, Government, educational institutions, and others to address them.

Introduction

Context of the Problem

In the office of the present, routine functions such as payroll, billing, inventory, and accounting are carried out by computer. In the office of the future, an enormously expanded range of functions will very probably be carried out by computer and linked via communications networks. In some scenarios, no "office" per se exists; office functions are performed by machines and human operators without close proximity to one another. One familiar technology in the office of the future will be word processing. In the future, documents will frequently be typed in one location and produced automatically at another. Processors themselves will have substantial stand-alone computing capabilities and will communicate with one another. Many printing shops will be replaced by "reprographics" installations using computerized typesetters, video data terminals for photo composition, and high-speed, non-impact printers. Computer output will be stored directly on microfilm or other recording media. Face-to-face meetings will give way to teleconferencing. All internal correspondence will be handled electronically, as will much communication with other organizations, and all these technologies will be interconnected via telecommunications.

These new capabilities mean that the office of the future will have to be organized and managed very differently from the present:

> Hierarchical levels can be eliminated, spans of control extended, middle management personnel utilized more effectively, better coordination introduced in responding to changing business conditions, etc. Thus, the Office of the Future concept is not just the automated office or the electronic office; rather, it is one in which new technologies give senior management the opportunity to consider entirely new approaches as to how best to organize, manage and control the enterprise.[1]

Together, these technological, organizational, and managerial changes promise dramatic increases in productivity in non-manufacturing sectors of the U.S. economy. They will occur as the economy undergoes profound changes that began early in the 20th century.

During this century, the United States marked its passage into the postindustrial era. In 1900, only about 25 percent of the

U.S. labor force was composed of white-collar and service workers, with the bulk of workers engaged in blue-collar (35 percent) and farm (40 percent) employment. By 1980, more than 60 percent of the labor force was working in white-collar and service jobs, with only a decreasing minority of workers employed as blue-collar and farm workers. As the white-collar workforce has grown during the past 30 years, particularly rapid expansion has been occurring in three job categories: professional and technical workers, clerical workers, and managers and administrators.[2] These trends are expected to continue through the 1980s and beyond.

A central feature of the contemporary employment setting is the emergence of information handling as the major task among workers:

> Gradually and almost imperceptibly, the U.S. economy since 1940 has been engaged in a transformation that is unique in the history of mankind. By the mid-1950s our working population was predominantly engaged in information handling: more people were involved in the manipulation of information than were employed in mining, growing crops, raising cattle, manufacturing goods, or providing personal services. The "information society" became in fact a proper expression of predominant societal characteristics.[3]

Those whose work contributes to the information economy include professional and technical workers, managers and administrators (the two classifications together are sometimes labelled "knowledge workers," despite the fact that managers "handle" most information orally), and clerical workers who support them. As the passage into the postindustrial era becomes more complete, the number of knowledge workers is expected to grow much more rapidly than the workforce average. Despite the massive introduction of electronic data processing equipment, some observers argue that clerical workers will not be displaced by computers and that many clerical jobs will evolve into different kinds of support positions in closer symbiosis with knowledge workers. Others argue that the new computer technologies will eliminate many clerical jobs (held primarily by women) and create positions paying only the minimum wage.[4]

Policy Aspects of the Problem

A key problem in the information economy is how to identify, obtain, and manipulate needed information effectively and efficiently. The explosive growth of the information processing industry since 1950, which accompanied the labor force shifts just described, created expectations of swift and easy solutions to this problem and of concomitant increases in productivity in these growing sectors of the economy. However, the expectations have been largely unfulfilled, with U.S. productivity growth actually declining. Indeed, U.S. labor productivity for all industries is increasing more slowly than in most other industrial nations, and growth in labor productivity in the private sector peaked in the mid-1960s.[5] Ever more powerful information processing technology still appears to offer promise of greatly increased productivity growth in the postindustrial United States, but current trends suggest that there is, and will continue to be for some time, a gap between expectations and reality. As Strassmann puts it:

> Clearly there is something amiss if diverting workers from industries with high productivity and effective use of capital—such as agriculture, mining, manufacturing, and utilities—into overhead jobs in business and government fails to increase aggregate economic performance as measured by accepted economic indicators.[6]

This paper describes the new computer and communication technologies that promise greatly enhanced productivity in white-collar and service work, examines some of the factors that facilitate and inhibit the introduction of these new technologies into the workplace, and suggests some actions that might be taken by industry, users, and Government to overcome barriers to realizing more completely the potential of the new technologies. In addressing these topics, a brief overview of the technological potential of devices and systems (for example, micro-computers, teleconferencing, electronic mail) is provided; the question of whether introduction of the new technologies is technology-driven or user-driven is examined; some of the major implications of the new technologies for human-machine interaction, the organization of work, and human interaction are identified; and some of the broader societal implications of the new technologies are suggested. Although the scope of the paper includes communications technology, the focus is on office automation, particularly on computers.

Trends and Developments

Approaches to Analyzing White-Collar Productivity

In the United States in 1980, more than half of those employed worked in an office. There are many organizations, such as banks and insurance companies, where almost everybody is an "office" worker. In manufacturing, retailing, mining, and other basic industries, office workers constitute less than 50 percent of the workforce. Nevertheless, even in these industries the percentage of office workers is increasing, and the introduction of robotics may cause the percentage to soar as production workers are displaced by automation. As the proportion of staff devoted to information exchange grows, productivity gains will have to come from the bulk of the people who work, the office staff.

According to one estimate, 60 percent of the $1.3 trillion paid for wages, salaries, and benefits in the United States in 1980 went to office workers.[7] The enormous proportion and amount of money paid to office workers will be a substantial, increasing incentive for industry to substitute capital for labor by automating the office. Furthermore, the capital to labor cost ratio in offices is currently estimated to be between one-tenth and one-twentieth of that in highly productive manufacturing industries, with the cost of office automation equipment actually falling. Given this it seems that introducing information processing equipment into the office would produce dramatic productivity gains. Manufacturers argue that business should find it virtually irresistible to substitute machine power for human labor. Nevertheless, the link between increased use of computers and communication equipment in the office and enhanced office productivity is not as direct as these arguments suggest.

One reason the linkage is, at best, indirect is that the appropriate level of aggregation—that is, the unit of output—by which white collar productivity should be measured is not clear. Productivity changes measured at the national level tell us little about which sectors of the economy are experiencing changing productivity growth. Differences in the nature of sectoral outputs make comparisons of productivity between even large sectors of the economy such as manufacturing and services difficult to interpret and possibly highly misleading. At the other extreme, productivity change measured at the individual level can also mislead, especially when new technology alters the structure of the work, thereby influencing group rather than individual productivity. Intermediate levels of aggregation such as industry or "office" (workgroup with specific mission) probably are the least misleading for purposes of estimating the potential and actual effects of new technology on productivity growth. Unfortunately, efforts to develop these kinds of data for the service industries are at a relatively primitive stage. Clearer linkages between productivity gains and office automation must await improvement in data, especially in service sector output measures at intermediate (workgroup) levels of aggregation.[8]

Attainment of Gains in White-Collar Productivity

Demand for computer and telecommunications equipment for office applications has developed more slowly than expected.[9] The office automation "revolution" is looking more like a gradual transition that will probably not reach fruition until the end of this century. Vendors of office automation technology currently are seeking explanations for the slow pace of acceptance.

Several reasons have been suggested for office automation's gradual penetration of computers, teleconferencing, electronic mail) is provided; the question of whether introduction of the new technologies is technology-driven or user-driven is examined; some of the major implications of the new technologies for human-machine interaction, the organization of work, and human interaction are identified; and some of the broader societal implications of the new technologies are suggested. Although the scope of the paper includes communications technology, the focus is on office automation, particularly on computers.

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Several reasons have been suggested for office automation's gradual penetration of in electronically supported work stations are not practical in the 1980s and perhaps not by the year 2000....As our knowledge workers devote more and more time to unstructured communications associated with the management of change instead of to well-defined computational or procedural tasks, the difficulty of changing tasks from manual to electronic processing will escalate....All this will probably happen gradually in the next 5 to 15 years, when the current concentration on word processing, text processing, and distributed computing will run its course. At that point, the era of the personal work station as the principal means for interorganizational communications for the majority of white-collar workers will be possible.[13]

The Technology

The progress of computer technology is impressive. It is awesome to realize that some handheld calculators in use today have more processing power than many computers in use in the 1960s. There are extremely versatile and powerful central processing units (CPUs) in widespread use today that occupy a space about the size of a stick of chewing gum. This same CPU power would have occupied a closetful of space no more than 15 years ago. The price-performance ratio of memory, including permanent memory, volatile memory, and direct access storage devices such as disks, has fallen at an even faster pace than the CPU, with a much more dramatic decrease in space requirements. Although this technology is the key building block for office automation, it is not essential to understand the hardware in order to examine trends in office automation. We need only assume that computer hardware will get ever faster, cheaper, and more versatile—a fairly safe assumption for the foreseeable future.

It is important, however, to understand the function of this technology in the office environment. Fortunately, several investigators have attempted to classify the use of computer systems in businesses, principally in the context of management information and decision support systems.[14] By considering these earlier classifications and given the purpose and context of office automation, we offer a typology of computerized office system functions as a means to this understanding:

(1) *Transactions*. At this level, fixed inputs are processed according to a determinate scheme to yield a highly structured set of outputs. This may be an order entry system, a payroll system, a bank card system, or even a word processing system. Transactions, in general, is a data-oriented function.

(2) *Analysis*. An analysis system uses computational, statistical, or, more generally, logical and mathematical techniques to manipulate an existing data base. A typical analysis system might use multiple regression to explore trends in data or analysis of variance to examine the validity of hypotheses. Other analysis systems in daily use allow searching of accounts for overdue payments or examination of perpetual inventories for economic order points. As with transactions, this is a data-oriented function.

(3) *Projection*. Projection systems may permit the user to evaluate the consequences of planned actions, add data into the system based on personal judgment, or search for solutions with certain constraints. That is, the user can explore the variety of outcomes through "what if?" types of entries, which are not necessarily tied to any data or information preexisting in the system. Many of the popular profit-analysis models are projection systems; most material requirement planning programs are of this type also. Interestingly, microcomputer programs such as the popular VISICALC and its functional equivalents are often employed in this mode.

(4) *Communication*. The final type of function of a computer system is that of communication. These types of systems act as smart conduits among individuals with access to the same computer, timeshare system, network, or storage media. Functions of communication systems include mail, messages, calendars, and data storage and retrieval in general.

Given this typology, the automation of the office can be seen not as the implementation of a monolithic technology, but as the introduction of several technologically based functions in succession. Although far from exhaustive, the following table provides some illustrative applications:

Table 1

A Typology of Computerized Office System Functions

Type	Function	User
TRANS-ACTIONS	Payroll	Staff
	Invoicing and Accounts Receivable	
	Inventory and Accounts Payable	
	Order Entry (Key-punched)	
	Word Processing	Clerical
	Perpetual Inventory	Staff
	Point of Order Entry with Confirmation of Stock Available	Sales
ANALYSIS	Goods Ordered Most Frequently	Staff
	Best Warehouse Location	
	Warehouse Routing	
PROJEC-TION	Profit—Simplified Model	Managers
	Profit—Interactive Model	
	Extension of Credit to Customers	Staff
	Orders to Stock	Staff
COMMUNI-CATION	Interoffice Messages	All
	Calendar Management	

During the early years of computers, from the first designs up to about 1974, the mainframe was all there was in the world of business. This was a big computer, which took up most of a floor in a typical office building and cost millions of dollars. Next to emerge was the *minicomputer*. At first this machine had a CPU with only a fraction of the power of the mainframe. However, integrated circuits advanced so rapidly that many minicomputers soon emerged with far more power than some of the mainframes. Then, in the late seventies, very large scale integrated circuits became economically feasible. This spurred the popular acceptance of the *microcomputer*. The microcomputer originally had a very limited memory, perhaps a 16,384 "word" capacity, and minimal processing power. However, in the last few years, even the microcomputer has become a behemoth in terms of memory and power. Today, some have millions of "words" of storage, hard disks, and processing power that equals or even surpasses some of the modern mainframes. Along some significant dimensions, the distinction between the mainframe, the minicomputer, and the microcomputer is blurred. Thus, the personal computer user, despite using a "simple" computer, can be very sophisticated. A wholesale infusion of today's personal computer users into the ranks of management may alter the office of the future more than any new hardware or software by itself.

Human-Machine Interaction

Symbiosis between the knowledge worker and his/her electronic work station—human-machine interaction—is one of the essential ingredients of the office of the future. The development of better hardware at ever-decreasing costs for automated office systems is expected to continue at its inexorable pace for the foreseeable future, but the parallel development of adequate software is proceeding somewhat less rapidly:

> The fruits of the electronics revolution are such that we can afford to do anything we want—if we can only program it. Software is the dominant challenge in office automation....Software will be the major development cost element for the foreseeable future.[15]

In particular, the development of techniques to interface computers and their peripheral devices into a human environment lags far behind other aspects of automation. This presents significant problems in effective office automation and may well develop into the major bottleneck in the technology's implementation. Four underlying trends are described in the following paragraphs.

(1) Hardware manufacturing costs are declining, but software development costs are rising. Increased manpower costs and increased complexity of software systems have, on balance, more than offset advances in effective programming tools. Recent advances in programming environments, structure editors, software engineering, and personal computing work stations may, however, mitigate the trend toward increasing software cost.

(2) The ever-expanding number of computer users is increasing at a much faster

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COMMUNICATION	Interoffice Messages	All
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> The fruits of the electronics revolution are such that we can afford to do anything we want—if we can only program it. Software is the dominant challenge in office automation....Software will be the major development cost element for the foreseeable future.[15]

In particular, the development of techniques to interface computers and their peripheral devices into a human environment lags far behind other aspects of automation. This presents significant problems in effective office automation and may well develop into the major bottleneck in the technology's implementation. Four underlying trends are described in the following paragraphs.

(1) Hardware manufacturing costs are declining, but software development costs are rising. Increased manpower costs and increased complexity of software systems have, on balance, more than offset advances in effective programming tools. Recent advances in programming environments, structure editors, software engineering, and personal computing work stations may, however, mitigate the trend toward increasing software cost.

(2) The ever-expanding number of computer users is increasing at a much faster

Furthermore: mature users can be quickly frustrated by too much "help."

(4) Well-designed, stylized command interfaces require user training but could be designed to achieve high functionality with low complexity. These seem to be best for mature or frequent users.

Interfaces are also required for technologically complex devices that are not computer-based work stations. However, the type of interface required depends strongly on the particular properties of each device. Uniformity of operating conventions across all software and hardware systems is clearly a highly desirable objective.

User Training Techniques. Thought needs to be given to methods for training users of new systems. Some casual users of computer systems whose time is a scarce resource (such as managers and scientists) will require interfaces that make no prior training demands. This clearly limits the scope of their ability to exploit new computer technology directly. For other users, a combination of forgiving, friendly interfaces and short, hands-on training periods is likely to prove much more cost-effective than either training all users to become computer experts or inventing and providing the ultimate, foolproof, natural (and as yet mythical) interface. However, little effort has gone into examining the best methods for training computer-naive people to become effective casual users of automated office systems. Although the tradeoff between laboriously developed, friendly interfaces and user training has not been quantitatively analyzed, the expected size of the user population, its frequency of interaction with the system, and the expected system lifetime appear to be determining factors of cost-effectiveness. How this tradeoff might be evaluated and who will pay the costs under each alternative are unresolved questions that merit investigation. Another dimension of the training issue involves consideration of a widely distributed training capability, one that incorporates the enormous variety of office situations and, thus, of training needs.

Human Interaction in the Organizational Context

We do not yet know how to restructure office work to take advantage of office automation technology. Indeed, variations in the nature of offices and of office work across and within industries virtually guarantee that the desired knowledge will appear piecemeal, made up of a series of contingent statements rather than a single, grand "theory." But the outlines of some of the consequences of the new technology for human interaction in the workplace are beginning to emerge. As technology provides more and more functions, knowledge workers (particularly managers) will be using terminals. This, for example, will alter the role of the secretary as the manager substitutes the computer for tasks previously reserved for clerical workers. The professional may, in fact, do his/her own "typing" at the keyboard while drafting and editing a document; final hard copy production becomes trivial. Alternatively, as more office automation is implemented, systems frequently are put in place under secretarial control. This, in itself, is an immediate impetus for changing the secretarial role and career path to management or creating, in the office context, a new intermediate category of paraprofessionals. The best analogy is in the legal field, where many paraprofessionals were secretaries. In their current jobs they use the same equipment and technology that they used previously as secretaries for routine legal work. People who are willing to become paraprofessionals are themselves in a more professionally oriented role.

As a larger proportion of our population uses a microcomputer at home or plays video games at the tavern, more will be willing to use a terminal at the office. These people may be very impatient if they are not provided with the capabilities of an office system to create text, do electronic filing, handle calendars, and receive electronic mail. We have become accustomed to an office system staffed by workers who are slow to change, but in the near future this may not be the case.

The office of the future may significantly alter the role of time in work. For instance, given the present physical document distribution system, nobody really knows when a particular individual gets a document unless it is hand carried with return receipt requested. This is relatively rare. Even within the internal mail system it takes a day or two to receive a document. In a multilocation organization, it often takes a week to be sure that every plant, warehouse, and sales office has received a particular document. Today people feel they need time to think about their response; some "buy time" by saying a letter is in the mail even before it has been prepared. Just as there is a certain amount of "float" in the present banking system, a "float" exists in the physical mail system. Of course, reducing transmission or transaction time alone may have little effect if decisionmaking capacity remains untouched.

As electronic filing and electronic distribution are implemented, management will know that information has been received by all of their staff. The electronic mail systems have the capability of notifying the sender that the document has been received. Thus, there will be a much higher level of expectation that the response will be returned within a specified time, such as 24 or 48 hours. This will be a much smaller "window" than is currently possible with physical mail. Having to respond more quickly can increase the pressure on individuals and might also result in a less carefully considered response. Doing things more quickly is not necessarily doing them better, yet speed rather than effectiveness of information may be how managers evaluate their staff.

On the plus side, time no longer affects communication when electronic mail and message systems are in place. A telephone conversation requires the simultaneous availability of at least two parties. Electronic messages can be sent and received without regard to such constraints. In addition, the new technology allows periodic reports and records to be updated until the last minute and produced at the punch of a button. This can reduce time pressure on analysts and writers, who can place more emphasis on the quality of their products. Conversely, it could allow them to turn out a sloppy initial product for repeated revision.

Another consequence may be a reduction in day-to-day human interaction. Individuals who can retrieve information from the system electronically do not have to ask their secretary or their staff to get the information for them. It is often in the very process of asking for information that management spends a few minutes discussing personal concerns and family activities. This is an important part of the human interaction that makes work a pleasant experience. If office workers interact with machines more exclusively, the office may assume a more sterile or factory-like atmosphere.

The advent of office automation, however, will not necessarily lead to hermit office workers, communicating only via their computer terminals. Such has not been the case at universities and industrial research environments where electronic mail systems have been functional for many years. In fact, electronic mail displaces interoffice memoranda more than it displaces face-to-face discussion or telephone conversation. Whether this will remain true as office automation spreads to other settings and as the restructuring of office work to enhance productivity growth proceeds remains to be seen.

The flexibility and freedom of the office of the future lead to another significant problem managers will face. How do you monitor what people are doing, especially if they are not doing it in a specified place at a specific time? In the past, managers were cognizant of almost all of their white-collar employees' operations. In an automated environment, lack of proximity and simultaneity of work may create new management tensions and dilemmas.

Anticipated Secondary Consequences

The so-called office in the home can offer striking opportunities or create a central problem in the technological age. Decreasing costs of terminals and communication are the key factors. As costs drop, the reach of the office will indeed extend into an individual's home. This will alter the workstyle for executives, as they would not be constrained by time when dealing with worldwide operations but would have to rethink how and when they use personal time.

An office in the home can represent almost the ultimate in energy savings as far as communication and transportation are concerned. Individuals will certainly get used to having a greater fund of information available to them through such information services as Teletext and Videotex.[16] Additionally, all of the office files can be accessed from a home terminal. Today people are able to use their telephone at home just as if they were in the office, and extensive teleconferencing is not far off. Increasingly, people may question the need to go to the office.

There are some people, of course, who want to get away from their homes. The tradition of mobility among nuclear family commuters may be resisted, even if homes are comfortable to work in and the same level of information and ability to communicate with people exists. Clearly, there will be intermediate steps between the office as we know it today and the office of the home. Such organizations as Satellite Business Systems and Bell Telephone are proposing to set up video conferencing centers where people would travel to some central site to take advantage of the facilities. They would not have to travel to another city to conduct a conference. Value added networks are being set up as well by a number of organizations to provide the facilities of electronic mail. These include GT&E's Telemain System, IT&T's Faxpack System, Tymshare, and Tymnet. Remote work centers also may emerge as intermediate arrangements between the office-at-home and a single, centralized location. The alternatives are clear, but the actual geographic distribution of office work in the future is not.

Energy costs will also affect the use of paper within the office. Paper costs are directly related to the energy involved in changing wood to pulp and then drying that pulp to make paper. So the cost of paper escalates almost as fast as the cost of energy. The office of the future can minimize the use of paper with displays and magnetic storage. Unnecessary printing can be avoided by revising and distributing information electronically and printing it only when it is needed.

In the past, management felt that office staff members, particularly principals, were not hourly paid workers. If a specific problem or project were being handled, people were expected to come in early and stay late until they could solve the problem. When working at home becomes a reality, there will be a whole new level of flexibility introduced into the office system. People could work at any time they wanted to, not necessarily in eight or nine hour shifts. Under these conditions, only the product will matter, not how it was produced.

Policy Options

The potential that technology holds for increased efficiency in information handling in the office setting has been documented, and the technology that promises to realize this potential is being developed. In a few instances it has been introduced on an experimental basis. Yet market demand for the new information processing and communication technology is developing slowly, more slowly than might be expected given the intensity with which the need is expressed, even accounting for the effects of a sluggish economy and surplus of labor. Realization of the benefits of a new technology at firm and industry levels (in terms of increased rates of productivity growth) requires translation of need into demand. In this paper, different perspectives that implicitly place the burden for action at different doorsteps have been described. In this concluding section, different perspectives are explicitly linked with different institutional actors, and some of the actions that might be taken to facilitate the introduction and use of new information handling technologies into office settings, assuming that such facilitation is a policy goal of the actor involved, are discussed.

One perspective currently focuses attention on problems associated with *implementing* the new technology. This is the process during which it is introduced into an organization and, over time, becomes part of organizational routine. To some, the pace with which the new office technology will penetrate the market is a function of how rapidly users, particularly managers, become acclimated to it, begin to recognize its benefits first-hand, overcome their technophobia, and adjust their work habits. This perspective suggests action by the marketing divisions of industry to develop improved indicators of the technology's benefits to the firm, to offer training programs and seminars to potential customers (particularly management), and to provide analytical support to firms and other organizations as they restructure work flows and responsibilities to accommodate the new technology. These strategies largely accept the technology as given and focus on user adaptation at individual and organizational levels.

Another perspective views the problem in terms of human-machine interaction. More rapid acceptance of the technology depends upon how completely and rapidly hardware and software can be developed to support more "user-friendly" information-handling protocols. Applied research activities now being conducted in industry and universities on such topics as fault-tolerant software systems, natural language codes, and voice recognition input devices are directed toward reducing this barrier to more rapid introduction of the technology. In the past, the focus on user friendliness largely accepted the individual user as relatively fixed and sought adaptations in the technology, generally through the software interface, to the user's skills, knowledge, and habits. We now recognize that as the user becomes more sophisticated, the user-friendly aspects of the system must adapt accordingly.

A third perspective emphasizes the organizational conditions that must exist before the new technology will be implemented extensively. This perspective arises less from the need for the organization to adapt to the technology than from the view that large, complex organizations must make fundamental changes in the way they manage information before the benefits of automated information handling can be realized. Very little is known about how this restructuring should occur, especially across the variety of different industries (including Government) in which information handling has become a major expenditure. A significant role for research therefore emerges, perhaps under industrial or joint Government-industry sponsorship.

The policy implications of office automation depend upon the pace with which the new technology is accepted in the marketplace. If the pace is rapid, then productivity gains (with salutary consequences for the national economy) will be evident. These will mitigate or perhaps reverse the decline in the Nation's rate of productivity growth, despite the fact that manufacturing contributes less and less to the gross national product.

Should this occur, however, a number of problems may emerge that may warrant attention by Government, industry, and educational institutions. As noted earlier, agreement does not exist on the consequences of office automation for office workers. If change is rapid, substantial unemployment of workers with one set of skills (for example, clerical) could exist simultaneously with unmet demand for workers with different skills (for example, analytical). Government may be called upon to ease the personal costs of worker displacement, perhaps by extending unemployment compensation to certain classes of workers. New job training programs that address the needs of both the unemployed and the agencies and firms seeking persons with new skills may be needed. To meet the demand for persons to work in the office of the future, equipment vendors may have to supply training programs as an integral part of the technology they sell. Alternatively, users of office automation equipment may bear the burden of training costs. In any event, in this fast-paced scenario, industry (both vendors and users) would have an incentive to supply training opportunities so that both sales potential and productivity growth potential can be realized. Government would work to retrain workers who could not easily meet new job requirements.

If the pace of acceptance is slow (at least initially), another set of policy issues arises. We may assume that relevant institutions such as individual firms, industry and trade associations, vo-tech schools, and public schools will be able to adjust quickly enough to keep labor supply and demand balanced. But costs will accrue to the Nation as a whole if productivity gains do not occur as rapidly as expected or desired. The public policy question then becomes: What steps, if any, should Government take to facilitate the spread of office automation? Also, what actions by other institutions could speed the pace of acceptance, thereby realizing expected benefits to both vendors and users of the new technology?

Again, different diagnoses of the problem of slow market penetration have different implications for action. Currently, implementation costs (both monetary and nonmonetary) are seen by many as a major ıese costs could be reduced through :dence of how the new technology :fit the firm and by better under- ȝ of the several behavioral and tional factors that impede accept- ey could also be reduced if vendors .g to bear the costs of training and support to firms desiring to restaff ucture themselves to take advantage :chnology. Vendor firms currently ucting research that seeks to improve lerstanding of the implementation Government could provide addi- ɔport for this activity by encouraging y-industry cooperative research on ›ct. Industrial and trade associations velop and offer continuing education ·s for clerical workers interested in ›ffice automation to their skills, and ‹gers interested in planning for office ion or actually using the new tech- ıemselves. Virtually anything industry ɔ reduce "computer naivete" among community would facilitate imple- on of the technology. Seminars, ɔrograms, handbooks, and hands-on rations would be useful contributions. ꞓ are other research programs that :nent could support to facilitate duction of office automation. Private ꞓ unlikely to undertake such work they could not capture sufficient to make it worthwhile. Government ɔonsor research that would identify ve structural forms that information ȝ could take in different industries ›es of Government agencies and heir consequences for enhanced vity. Such research programs should work on definitions and measures luctivity for white-collar workers, y knowledge workers and managers. ·on of the Government's own ex- ꞓs with office automation might also elpful, as would evaluation of state- ırt installations in industry and uni- omputer science departments. Gov- t could study needs for information ·rs and support personnel and pro- ꞓ data to industry and educational ›ns. Finally, the Federal Government ıpport the development of software ds for office automation that would provisions for collecting data relevant to information system management research.

Regardless of the pace with which office automation proceeds, educational institutions must move to ensure computer literacy, just as they now address reading, writing, and arithmetic. But there is little agreement on how to address this problem, and there are few resources for experimentation. Schools from the elementary level through the university are not succeeding uniformly or satisfactorily, and successes achieved in one school are not communicated effectively to others or easily adapted by them. Thus, the first priority for all schools should be to determine reasonable objectives for computer literacy and support their attainment with substantial resources. In addition to offering new and modified curricula, universities and technical schools should develop continuing education courses, perhaps in conjunction with industry, directed toward information managers and support personnel. Whether the office of the future becomes pervasive in 15 years or in 30, the next generation should be computer literate to take full advantage of the benefits of the new office technology and to mitigate some of its possible costs.

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Fostering The Use Of Advanced Manufacturing Technology

Abstract

Manufacturing processes are a major factor in international economic competitiveness. In recent years, the United States has lagged behind other industrialized nations in the diffusion and implementation of advanced manufacturing systems. Many analyses have pointed out certain macroeconomic variables contributing to this lag; however, difficulties in *implementation* of these systems at the factory level, while equally important, have not been adequately addressed.

Several new technologies, including robotics, computer-aided manufacturing, group technology, and flexible manufacturing systems, are particularly crucial to economic competitiveness. These systems must be seen as complex sociotechnical phenomena, involving major changes in corporate strategies, organizational design, and human resources. For example, their implementation involves interactions among functional units within the firm, with effects that are radical rather than incremental; full implementation often takes years. Especially relevant to decisions about manufacturing technology are anticipated effects on the skill and responsibility profiles of workers, including the need for retraining, involvement in operational decisionmaking, and job redundancy.

Given the difficulties of implementation, current technology transfer efforts are probably inadequate. Shop floor involvement in implementation decisions is crucial, but often missing. Federal efforts in the transfer of advanced manufacturing technology have been uneven at best, particularly since much Federal R&D is mission-oriented with an emphasis on defense requirements. Universities have been reasonably active in research and development for new manufacturing technologies, but have not adequately addressed dissemination and implementation issues. The efforts of professional associations and societies have been considerable, but have been largely disaggregated. Given the need for widespread implementation of these technologies and the limits on current technology transfer, increased efforts reflecting a systems orientation by both government and private concerns will be required.

Introduction

One prominent economic and social issue with significant science and technology implications is whether the United States' position as a major manufacturing power will continue to erode over the next decade. Evidence is mounting for the critical importance of manufacturing to economic recovery and productivity. In the early 1970s, it was often argued that the decline of U.S. manufacturing reflected a "natural" movement toward a service economy. It was widely expected that service and knowledge-generation industries would supersede manufacturing in importance, just as manufacturing had once superseded agriculture. This picture has not been sustained thus far; the decline of productivity growth in manufacturing has continued, and the service economy has not grown at a rate sufficient to compensate.

During the past 20 years, foreign competition—particularly from Japan and Western Europe—has resulted in major inroads into domestic markets traditionally dominated by U.S. manufacturers. Especially hard hit have been consumer electronics, automobiles, basic steel, textiles, and footwear. The impact is not evenly distributed geographically; States with the highest current rate of unemployment are those with the heavy concentrations of traditional manufacturing industries. But the effect is spreading to other areas. Even in the semiconductor industry, long considered the preeminent preserve of American technology, the United States is being hard pressed by Japanese competition.

Many factors—technological, economic, and political—are involved in these events, including the growth of multinational companies and the consequent dispersion of economic activity around the world, the increasing costs of domestic capital, and the use of "dumping" and other unfair trade practices and even nontariff trade barriers imposed by foreign competitors. Different industries have been affected in different ways, but a common denominator is that our manufacturing facilities are not being replaced by sociotechnically innovative and efficient operations. As one indicator of this relative disadvantage, a survey by the *American Machinist* (1978) indicates that of the seven industrial nations studied, the United States has the lowest percentage of machine tools under 10 years old; Japan, for example, has twice the U.S. percentage of newer tools.

The last decade has witnessed tremendous advances in the development of new manufacturing technologies that could have contributed to U.S. competitiveness even in the face of wage and raw material cost differentials, protective trade policies, and differences in the cost of capital. These include robotics, computer-aided design and manufacturing, group technology, flexible manufacturing, and various management and control systems associated with these technologies. There are also technologies on the horizon (for example, artificial intelligence) that will qualitatively extend the array of ways to produce a product.

For various reasons, the United States has been slow to install and use such techniques. While much of the early development of robotics was done in this country in the 1960s by such companies as Unimation and AMF, Japan has come to be the undisputed world leader in the deployment of robotics technology. Since the introduction of the first robots into Japan (by a U.S. firm) in 1967, the use of robots has grown rapidly. By 1981 there were over 14,000 robots in use in Japan; estimates for the deployment of industrial robots in the United States and Western Europe are approximately 5,000 and 3,500 respectively (Robotics Institute of America, 1981).* Japan's leadership in the use of robots and related technologies is not generally disputed. As an illustration of radical possibilities offered by these technologies, Fujitsu Fanuc recently built a factory that can be left essentially unmanned during evening "ghost shifts." The plant has 29 work stations, 7 of which are equipped with robots, and 22 of which employ automatic pallet changers. The plant also has automatic warehouses, for both materials and finished subassemblies (Yoshikawa, Rathmill, and Hatvany, 1981).

Given these rapid technological developments and the increasingly frequent demonstrations of productivity gains in both foreign and domestic plants using these techniques, why have most U.S. manufacturing firms lagged in adopting and implementing them? One set of explanations currently offered is largely based on macroeconomic arguments involving taxes and related incentives for investment in new technology. The macroeconomic dimensions of R&D investment have been widely discussed (Annual Science and Technology Report to the Congress: 1981), and many changes have already been made in the U.S. Tax Code that will presumably address these and other investment constraints.

But such remedies operate at a rather high level of abstraction and aggregation and are by no means targeted at manufacturing technology directly. In fact, the economics of advanced manufacturing systems operate at a very micro level and are not well understood by most corporate decisionmakers. The nations where these technologies have enjoyed greater diffusion tend to have implemented much more focused economic interventions based on promoting the technology directly rather than through the manipulation of overall resource constraints on firms. There is little empirical or theoretical reason to assume that unfocused incentives will more than marginally affect the deployment of technology.

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tools; custom printing, tailored clothing, and other product lines where there are limited numbers of potential purchasers with a particular set of product needs. Job shops tend to be small in size and employ a large proportion of highly skilled workers.

Batch production involves runs ranging from 200 to 20,000 in size, although the absolute size of the production run is less important than the fact that the production facility needs to be changed at frequent intervals for different product lines. For example, a firm may set up a production line to produce several hundred electric motors of one size, and then in a matter of days or weeks convert that line to assembling a motor of an entirely different size. Machines and equipment tend to be relatively unspecialized, and a mix of skilled and unskilled workers is required. Products typically manufactured in batches include general-purpose machine tools; major household appliances; ready-to-wear clothing, books, furniture, and some types of industrial equipment. There are also "batch-flow" processes, such as the production of ice cream and cosmetics. Batch production accounts for over 35 percent of U.S. manufacturing (Gerwin, 1982) and tends to involve medium to large firms.

Mass production involves the continuous production of identical items, with high volume and the use of single-purpose machines and equipment. Demands on worker skills are generally low; U.S. mass production industries usually consider labor an easily replaceable commodity. Examples of mass production industries include automobiles, electronics, small household appliances, light bulbs, and nails. Mass producers tend to be large industries.

Several types of new technology can fit into this general pattern of manufacturing. Four types of advanced manufacturing systems will be considered here: robotics; computer-aided manufacturing (CAM); group technology; and flexible manufacturing systems (FMS). Although in practice these categories tend to overlap, (for example, robots are often a part of flexible manufacturing systems; and group technology is in many ways an essential ingredient of both CAM and FMS); they are discussed separately, since they employ rather different sets of equipment and have different behavioral, economic, and organizational implications.

Robotics Technology

The Robotics Institute of America (1980) has defined a robot as:

> A reprogrammable, multifunction manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks.

Robots may range in complexity from simple "pick-and-place" machines, designed primarily for materials handling, to complex machines possessing sufficient motion flexibility and sensing capability to emulate and often surpass the performance of a human worker at particular repetitious tasks. Early U.S. research and development of robotics was done during the 1950s, and the first industrial robot was installed in a U.S. factory (General Motors) in 1961. The major U.S. producers of robots are Unimation and Cincinnati Milacron, whose sales constitute approximately 70 percent of the American market. However, several other major firms are currently entering the field, and, as noted earlier, the Japanese presently dominate the world production of robots. There are now between 130 and 140 firms in Japan making robots, as opposed to roughly the same number in the rest of the world (Aron, 1982).

Robots range greatly in size and breadth of application. It is possible for robots to be installed either at single work sites or at many sites simultaneously; the "robotization" of a manufacturing plant can be approached piecemeal. Robots range in price from approximately $50,000 to $200,000. According to an industry source, robots have been installed in a plant employing as few as two dozen people. One impetus for the installation of robots has been to displace workers in areas when there are significant health and safety hazards and the cost of protecting the workers is considered prohibitive.

Computer-Aided Manufacturing

The initial move toward CAM was numerical control of machine tools, developed in the

1950s largely at the Massachusetts Institute of Technology (MIT) (Ettlie, 1971, and Groover, 1980), where the U.S. Air Force funded a project to improve precision in jet aircraft fabrication. The complexity of machining necessary for modern combat aircraft had put tremendous strains on existing control technology. MIT's solution involved automatic control of machine tools by a punched paper tape; airplane wing panels were milled to specifications on a preprogrammed, high-speed machine.

The development of small computers and microprocessors led eventually to the replacement of control by paper tape to control by electronics. The first phase in this development involved direct numerical control (DNC) in which a single large computer controlled a number of machine tools by hard-wired connections. As computer technology evolved, particularly with greater miniaturization, it became possible to have a single microcomputer in control of each machine. This led to computer numerical control (CNC) and enabled even greater control over the production process by allowing feedback on tool wear, greater use of sensors, etc. CAM has often involved combining these techniques by linking single machines' dedicated computers to a larger central control computer to schedule operations and related intermachine flows. In addition, it is often linked more or less directly to computer-aided design (CAD) systems.

Group Technology

In many ways, group technology can be considered an organizational or technical management precursor to flexible manufacturing and CAM systems. Group technology is more an organizational construct than a set of hardware. Its purpose is to bring the economies and benefits of mass production to small-scale manufacturing, down to the level of the job shop. Procedurally, it involves the categorization or grouping of parts on the basis of design and manufacturing similarities. Once a group of parts has been identified, a corresponding "cell" of machines performing interrelated functions can be dedicated to the production of that family of parts. Advantages in decreased set-up time are considerable, and productivity increases of major proportions have been reported (Gettleman, 1975; Gallagher and Knight, 1973; Wilson and Henry, 1977). Group technology in its present form began in Europe, including extensive work by the Russians, but many of the concepts and techniques of group technology derive from the work of an American—Frederick Taylor—in the 1920s. Group technology has many and varied applications in the machine tool industry, but these methods have not been extensively implemented in U.S. firms.

Flexible Manufacturing Systems

Flexible manufacturing systems are in many ways outgrowths or extensions of developments in group technology, computer-aided manufacturing, and robotics. As indicated above, early numerical control applications usually involved a single function such as drilling or shaping. These systems evolved so that tools could be changed and different types of machines could be linked together sequentially by materials-handling capabilities (for example, pick-and-place robots), all controlled, monitored, and serviced by computers.

One example of a flexible manufacturing system in the process of development is the Automated Programmable Assembly System (APAS) created by Westinghouse Corporation. The APAS demonstration is focused on the assembling of small electric motors, which historically have been batch-processed throughout the world. The APAS assembly line involves the linking of robotics, robotic workstations, advanced optical sensors, automated materials handling, and overall computer control into a completely automated assembly system. Most importantly, the system is "reprogrammable," such that motors of different sizes can be assembled literally at the flick of a switch. Another example of an FMS developed under Government sponsorship is the Automated Manufacturing Research Facility being developed by the National Bureau of Standards. This demonstration will involve an integrated series of machining and inspection stations with particular applications for small shops.

FMS exists at present more in theory than in widely deployed and developed applications. According to one industry analyst, there are less than 20 FMS systems in operation in the United States, and planning and installation currently requires something on the order of 2 to 5 years.

Problems of Use

As we have suggested, the availability of technical knowledge about advanced manufacturing systems has not resulted in their widespread adoption and use in the United States. It is necessary to look at the decision processes of individual firms to understand some of the problems involved and how they might be addressed. The social and organizational dimensions of technological change are as critical to its adoption and use as its technical dimensions and deserve as careful an evaluation.

In recent years, a body of knowledge has emerged about the process of innovation, and this can be applied to decisions involving technology. To understand innovation, technologies must be considered not only as collections of hardware, but as *knowledge* embodied both in the machines themselves and in the software, control, and organizational systems necessary to operate the technology effectively. Defined thus, the deployment of manufacturing technology can be seen partly as a knowledge dissemination and utilization issue.

The innovation process literature has recently begun to view technology transfer as moving through several separable stages, from initial awareness, to evaluation and deciding, to adoption, and, finally, to implementation. The transition from adoption to implementation is likely to be as critical for success as the dissemination of knowledge, but it has received much less attention. Up to the commitment point, knowledge dissemination is primarily a cognitive and intellectual activity that involves learning about the innovation. Implementation, by contrast, involves the expenditure of human and material resources and behavioral changes at many levels of the organization. Thus two separable knowledge transfer issues are involved: transmitting information that might lead to adoption and providing detailed operational information about putting the innovation in place.

An adoption decision is usually premised on management's perception that an innovation is more profitable or effective than existing practice, and thus there is a reciprocal role for vendors to make potential users aware of new technologies. The opportunity for users to observe real-time installations and demonstrations (essential for technologies of this complexity) is quite limited, particularly for smaller firms. Since the potential for marketing is usually greater with large firms, smaller firms may get less access to information about new technologies. While an adoption decision is usually fairly easily identified in space and time, implementation is not the result of a single decision but rather a whole series of decisions frequently made by different people in different places.

A key concept in understanding implementation is to recognize the impossibility of separating decisions about hardware and economics from their implications for the social behavior of those using the hardware. Engineers and technical designers often make critical decisions about social/organizational issues, such as how people will be divided into groups, how many people will be in these groups, and where individual workers will be located (Davis and Taylor, 1976), although often they are not aware of the implications of their choices. Thus, the adoption and implementation of even a simple pick-and-place robot is a set of complex sociotechnical processes involving many different people from many different groups in the firm and, thus, subject to evaluation from many points of view.

The empirical literature dealing with the problems of either dissemination or implementation of major technological systems is limited. Much of the traditional literature on innovation processes has assumed that implementation of technology follows naturally from decisions to adopt or purchase. The literature pertaining to the implementation of industrial innovations is especially meager, and studies of the implementation of manufacturing processes are rare. For a recent review of implementation studies (Scheirer and Rezmovic, 1982), only

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The pervasiveness of organizational effects attributable to manufacturing systems also has implications for leadership and decisionmaking pertaining to implementation. Since the implementation of such systems as CAM cuts across different functional units, it is probably unwise to give leadership of that implementation to any one function. One analyst has called for the assignment of a "process champion," who would have leadership responsibilities for implementation of such new technology across various functions in the company (Gerwin, 1982).

A process champion cannot operate in a unilateral or authoritarian manner. One of the more consistent findings in the innovation process literature is that adoption and implementation of complex technologies is facilitated by participative decisionmaking (see, for example, Tornatzky, et al., 1980). For the implementation of complex manufacturing systems to "stick," individuals from many different levels and functions within the firm will need to be involved in planning and decisionmaking. Often this will go against the prevailing organizational climate and may actually lengthen the implementation process.

However, it should be noted that our foreign competitors have become quite aware of the role of worker involvement in the improvement of process technology. In many ways, the quality circle movement in Japan has been an important factor in the advancement of manufacturing processes. Analogously, European nations have been acutely aware of the relationship between the new technologies and worker involvement in their use (Norges Offentlige Utredninger, 1980). Worker involvement can be used to assist implementation planning, and indeed many initiatives for installation of advanced technology such as robots have come from the shop floor. Many U.S. companies are involved in Quality of Work Life (QWL) efforts, which may have similar repercussions on the improvement of process technology through participative decisionmaking and planning. For any of these worker involvement programs to be effective, the participation must be substantial and significant on the part of both management and labor. To the extent that they are seen as ways to manipulate workers rather than to take them seriously, they will fail.

Longitudinal and Strategic Aspects of Manufacturing Technology

As we have suggested, the implementation of such systems as CAM, group technology, or robotics cannot be considered as merely a routine capital investment decision. Full implementation may take *years* (such as in the case of FMS) and must be well integrated into a strategic vision for the firm. In addition, the costs of adoption and implementation and the benefits from use of manufacturing technologies are not easily quantifiable in advance. Decisions may require as much an act of faith as a thorough economic analysis.

Unfortunately, the application of such strategic vision of manufacturing technology has been distinctly rare in American industry of late. Rapidly accumulating empirical and observational evidence (Hayes and Abernathy, 1980) suggests that a lack of strategic planning has serious implications for either adopting complex manufacturing systems or their successful implementation. Several factors have been identified as contributing to this lack of vision. In the last few decades, corporate managers in the United States have been more likely to have financial and legal rather than technical backgrounds. It has been suggested that this trend has stemmed from the greater emphasis in the last 20-30 years on matters external to the firm, particularly interactions with government—interactions focused more on law and money than on technology. Thus, the trend may well have had short-term surv val value. But it has also imposed costs. There is a greater preoccupation with short-term profits and decisionmaking, a dominance of a marketing orientation, and an increasing tendency toward corporate mergers. All of these trends have exacerbated a split between shop floor manufacturing technology and corporate strategy, and this split has made it difficult for managers to understand the implementation impacts of their strategic choices—or the opportunity costs of their *lack* of choices.

Sociotechnical Aspects of Implementation

It is increasingly apparent that implementation of advanced manufacturing systems will permanently change the nature of work and of the workforce in industry. Although the extent to which these technologies will produce net job losses or gains has yet to be determined, it is quite clear that the nature of job skills needed in manufacturing will change dramatically. Traditional mass production has treated workers as low-skilled operatives who are easily replaceable; the "second industrial revolution" will demand workers with multiple skills who will be heavily involved in maintenance of the new technologies, information transmission, and technologically demanding tasks. It will also probably require fewer of them. The shrinking size of the primary labor market is a fact with rather profound social policy implications, which are as yet largely unexplored.

Confronted with this reality, U.S. corporations will have to make a basic choice between retraining employees or simply replacing them. Interestingly, much of the high-technology manufacturing component of Japanese industry has thus far kept its commitment for lifetime employment and has invested heavily in worker retraining and skills upgrading. This high job security may actually contribute to innovativeness, as workers not confronted with job loss may more readily accept changes. In turn, management faced with a permanent workforce will need to explore ways to maintain and increase productivity.

Changing the skill and responsibility profiles of workers will likely have implications for the distribution of power and decisionmaking within the company. The center of influence may shift to those areas where the new sophisticated process technology is being employed on the shop floor. American manufacturers have tended to utilize work organizations based on hierarchical leadership and specialized job classifications in conjunction with advanced manufacturing systems. This probably reflects an attempt to apply management principles that are traditional in batch manufacturing. However, the nature of the new equipment may be sufficiently different from typical stand-alone machine tools that an alternative work organization may be in order. An integrated system is characterized by relatively sharp boundaries at either end and a continuous flow of material within the borders. It is therefore more akin to process manufacturing than batch manufacturing. This suggests that a work organization based on the group as the fundamental unit may be more appropriate than one based on the individual.

One possibility to consider, according to sociotechnical systems theory, is a joint work group of operators and loaders that does away with their separate designations. Each participant would have an opportunity to share in all or most tasks. The group would be responsible for the complete cycle of loading, monitoring, and unloading as well as some repairs, tooling, and supervisory functions. Consequently, task identity, meaningfulness, and feedback on performance from coworkers would be increased. Job rotations would augment autonomy and participation in work-related decisions. European manufacturers appear to be more willing to experiment with new approaches to work organization that might provide a better fit with advanced manufacturing technology (see Taylor, 1977, for illustrations).

Efforts to understand new job skill requirements will go hand in hand with implementation of the technology per se if maximum benefits are to be realized. Like technical choices, social and organizational choices related to implementation are frequently driven by the technology (for example, size, structure, and composition of work group), but always with the potential to shape it reciprocally. The more this interaction is understood and planned for, the less will be the stress on the system and the better the results (Reinke, 1982).

Technology Transfer Strategy and Tactics

It should be clear that the dissemination and implementation of advanced manufacturing systems will not just happen, but will likely be a painful and stressful situation for most organizations. Some of this stress can be reduced through strategic planning for implementation. For example, the relationship between the equipment vendor and the implementing firm is much more intensive and extensive than in other capital investment programs. The vendor should be willing to work closely with the adopting company—and in turn the adopting firm must be willing to devote resources to understanding the technology and its implications. A simple turnkey approach to the technology is not likely to be workable for either vendor or adopter. There is evidence that the more complex the technological system being implemented, the less viable the turnkey approach (Cooke and Malcolm, 1981).

Worker participation is crucial in implementation strategy. Some programs have heavily involved lower level staff in new plant design and the implementation of advanced manufacturing systems (Gustavson and Taylor, 1982). More of this will probably occur as management structures oriented toward traditional linear and hierarchical technology are replaced by managerial practices oriented toward advanced manufacturing systems and the lower level discretion they require. Given the extensive involvement of lower level staff in successful implementation, acceptance of information about new technologies might be enhanced by focusing dissemination efforts at that level. For example, in an automobile plant being established in Tennessee, a large percentage of the new workforce was flown to the home plant in Japan to become familiar with the manufacturing processes to be used there.

The major argument for explicit attention to implementation in technology decisions is that it will help both managers and workers avoid some surprises. While new technology is inherently uncertain in its effects, there are many potential contributions of implementation analysis that can guide technological strategy. In general, the Japanese have been better at applying these principles than have Americans, for reasons partly cultural and partly deliberate. Japanese emphasis on consensus-building has incorporated delays and trials into the process, explicitly recognizing that multiple decisions are involved. By contrast, American managers frequently treat technology decisions as simple choices and set artificially short timetables for implementation. The almost inevitable disappointment with the results tends to be interpreted more as a reflection on the technology than on the inadequate implementation process. There is no doubt that many managers have interpreted as technical deficiencies problems that in fact derive from the shortcomings of their own strategic organizational choices.

Programs to Assist Technology Transfer

Efforts to assist firms in understanding and using advanced manufacturing technology are emerging from three sources: the Federal Government, university research centers, and private nonprofit educational and professional associations. The nature and scope of these efforts will be described below. Few if any of these activities appear to recognize the systematic properties of either the technologies or the client systems with which they work. In many ways, these groups are more concerned with the hardware than with the software, organizational, or human resource aspects of manufacturing technologies. As Noble (1979) indicates, the development of advanced manufacturing systems has tended to be left to "industrial technocrats...and self-serving computer jocks."

The Federal Role in Manufacturing Technology

There are approximately one dozen Federal programs focused on advanced manufacturing systems. These programs are scattered always with the potential to shape it iprocally. The more this interaction is ierstood and planned for, the less will the stress on the system and the better results (Reinke, 1982).

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The Federal Role in Manufacturing Technology

There are approximately one dozen Federal programs focused on advanced manufacturing systems. These programs are scattered members and nonmembers. Similarly, the Robotics Institute of America supports conferences and workshops oriented around robotics technology. At a more general level, the Society of Manufacturing Engineers has a heavy investment in these new technologies and has been quite active in organizing symposia, training, and general knowledge transfer.

One problem with these training/dissemination efforts has been that they have addressed general technical issues rather than specific operations at particular sites. They also tend to treat only the hardware aspects of implementation, which may be the smaller (if more manageable) part of the problem. Implementation issues are often likely to be idiosyncratic and unpredictable in nature and need to be addressed on the shop floor. This aspect of assistance has been largely left to vendors of equipment, and their performance has been uneven. Marketers, like manufacturers, tend to take a short-term view of their clients. What needs to be determined is how they might be induced to take a longer view, and if there is an appropriate dissemination and implementation assistance role for Government or Government-supported activities.

National Implications and Policy Options

In some senses the issues raised in this paper illustrate the limitations of traditional Government policy levers. If adoption and implementation of advanced manufacturing systems are phenomena played out in the context of the firm itself, it is only partially affected by interventions at the industry or sector level. Management practices and strategies seem heavily implicated in the successful implementation of these technologies, as does knowledge transfer regarding the technologies themselves. It is unlikely that Government actions in such areas as taxation could substantially alter the incentive structure and consequently the strategic vision operating in American manufacturing within anything like the time horizons required. This would require a much more detailed taxation package than has previously been enacted, one heavily oriented toward rewarding productivity enhancement and implementation of advanced process technologies. This is an extremely microlevel manipulation of economic policy, and it is likely to be looked on with disfavor as an excessive intrusion into the operations of market forces.

There does seem to be a legitimate Government role in two particular areas beyond the traditional (and still needed) support of basic and applied research leading to technology development. The first is in knowledge transfer and dissemination of technological information. Current technology transfer and implementation assistance is extremely scattered, and Federal agencies involved in the development of manufacturing technologies have not been given either a clear mandate or sufficient resources to promote civilian implementation.

The barriers to such an effort are more conceptual and ideological than practical. Programs of this type would radically alter the traditional Government posture toward technology development. In the past, the Government has restricted itself to support of research and early development and has depended upon market forces to enhance dissemination. This is the classic "demand-pull" approach. In contrast, an aggressive coordinated technology transfer program (somewhat akin to agricultural extension) would imply that Government had made a strategic choice to "push" a family of technologies. While this would be unprecedented in regard to manufacturing technology for the United States, it would more closely approximate the posture taken by such countries as Japan and West Germany.

An essential corollary of a "technology push" posture would be explicit attention to issues of worker displacement and retraining. While the extent of worker redundancy produced by the new technologies is unclear, it is virtually certain that dislocations of labor will occur. Such options as guaranteed employment, incentives for retraining, and employee gain-sharing of productivity growth should be considered in this context (*Business Week*, 1982). Moreover, policy should recognize that job creation and new industry are priorities.

Another area of modest Federal activity would be research to improve understanding of the dissemination and implementation processes. As noted several times, the processes by which complex technologies are adopted and implemented are not well analyzed, nor have they been translated into action programs in any systematic way. It should again be emphasized that advanced manufacturing systems constitute very complex innovations for adopting organizations, and we could understand that innovation process itself considerably better than we do now.

The bottom line is that one is unlikely to be able to implement advanced manufacturing technology adequately if it is viewed as just another machine or tool for doing what one is doing in the same way as at present. While these systems are potentially extremely productive—and probably essential to the survival of the American economy—they are radically different from present technologies in crucial ways. Taking advantage of advanced manufacturing capabilities is a process that will require considerably more, and more systematic, attention to the phenomenon of deployment than has heretofore been generally in evidence in U.S. industry. It will also require a significant change in how managers view work and workers. The types of technical and managerial control required by advanced manufacturing systems open up all kinds of new possibilities for developing organizational structures and processes with both economic and human benefits. This is an area where the U.S. Government must think about its role in enhancing such transitions, with at least as clear a vision as that of its international economic competitors.

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