THE CHANGING TIDE

FEDERAL SUPPORT OF CIVILIAN-SECTOR R&D

November 1, 1981

(NASA-CR-165048) THE CHANGING TIDE: FEDERAL SUPPORT OF CIVILIAN-SECTOR R AND D (New York Univ.) 151 p HC A08/MF A01 CSCL 05A
N82-14985
Unclas
G3/85 08581

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This report is based on research supported by the National Aeronautics and Space Administration under grant NSG7636. The opinions, conclusions, and recommendations expressed herein are those of the authors and do not necessarily reflect the views of NASA or its employees.

Acknowledgements

The authors wish to express their appreciation for the support and helpful comments provided by Mr. Leonard A. Ault, Acting Chief, Dissemination & Analysis Branch, NASA. We were helped considerably by the encouragement of Dr. John D. Holmfeld, Science Consultant, House Committee on Science, Research & Technology, and by Mr. Steven A. Merrill, Staff Member, Subcommittee on Commerce, Technology & Space, Senate Committee on Commerce, Science & Transportation. We are also grateful for the cooperation and guidance provided by Dr. Richard A. Meserve and Mr. Phillip M. Smith, then Senior Policy Analyst and Associate Director for Natural Resources & Commercial Services, respectively, of the White House Office of Science and Technology Policy.

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*Forthcoming in 1982 from Pergamon Press.

EXECUTIVE SUMMARY.

Objectives and Approach.

This study is intended to provide perspectives on the involvement of the federal government in civilian-sector R&D -- how it evolved, how it has performed, and what guidelines can be suggested for improving future effectiveness. These judgments are informed from a number of sources -- consciously selected so as to view these issues from differing perspectives -- but are disciplined by a coherent framework established by the authors. The inputs were:

1. Reviews of past trends and current status of federal science and technology policy, industrial research, and economic theory related to technical change.

2. Analysis of recent experimental initiatives by the federal government to support civilian-sector R&D through various approaches.

3. Group discussions and individual interviews with industry executives and government officials to obtain their judgments on what has worked and what has not, and on suggestions for improved procedures and program concepts.

4. Substantive studies and analyses of the influence of federal actions on technical change in seven key industries -- aviation, pharmaceuticals, computers, housing, automobiles, agriculture, and semiconductors. These were conducted by a group of distinguished economists, and provide a firm base of historical anecdotal experiences over a range of industries. *

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* Published separately as Richard R. Nelson, ed., Technical Change in U.S. Industry: A Cross-Industry Analysis, Elmsford, N.Y.: Pergamon Press (forthcoming in 1982).

The final presentation is in two volumes, of which this is the first. The industry-sector studies will be published separately, although its table of contents is printed here and a review of its contents is given as Chapter III. This first volume is intended to stand alone and its conclusions are informed by, but not limited to, those of the separate industry-studies volume. A summary listing of criteria to be considered in future federal support of civilian-sector R&D is given at the end of this Executive Summary.

Contents.

The years since World War II have seen two distinct trends -- two changes of the tide -- in policy towards direct financial support for civilian-sector R&D.

Since World War II, a steady growth of activism in federal funding for R&D evolved from the support of technical infrastructure to a massive expansion of public-sector R&D for areas -- e.g., defense, space -- in which the government was the final customer. In the '60s and early '70s, the first philosophical shift occurred, placing increasing emphasis on areas in which the government was not the final customer -- transportation, energy, housing, communications, materials. This raised some very specific policy issues, involving such things as program selection, priorities, conduct of research, and transfer to the private sector -- in short, the effectiveness of the federal involvement.

Today, a second shift is underway. Many of these more specific issues remain. But they -- along with some newly-important larger issues -- must now be understood in relation to the directions being established by the Reagan administration since January, 1981. Nowadays, the question of whether a federal activity is called for at all precedes the question of which activities will be most effective under which conditions. Inevitably, it seems, there will be a retrenchment in certain types of R&D activities, an ebb in those functions performed by the federal government that had emerged almost as a by-product of the R&D momentum built up before 1970.

This current change of tide can be guided by an understanding of how we arrived at our present position, by what we can learn from historical experiences, and by the judgments of senior executives from both government and industry.

The present status of the total civilian-sector R&D effort in the U.S. derives from three main streams of activity and thought:

First, the federal government emphasized support for technical infrastructure -- basic research, generic technology, training of scientists and engineers. It devoted very considerable funds to the technologies and facilities required for public-sector activities -- national security, space, health. And it moved somewhat into direct support of civilian-sector R&D.

Second, industrial research grew steadily, so that corporate funding of R&D is now about $33.9 billion, or about 47 percent of total national R&D expenditures. Thus, the private sector became relatively self-sufficient in generating the R&D it needs to support present products and processes as well as growth of new business.

Third, economic theory drew attention to the social value created by private R&D; to the implications for R&D

investment of the appropriability (or lack of appropriability) of an individual corporation's R&D; and to the contributions of R&D to industrial productivity and international trade. This work was used as philosophical justification for federal support of civilian-sector R&D, and has served to focus attention on the importance of a healthy technical foundation for both public- and private-sector objectives.

These trends serve to describe where we are on a national scale. Further appreciation of the effects that have been felt by specific sectors is provided in our detailed examination of seven industry sectors. The influence of federal actions and policies on technical change in each of these industries gives us a rich background of specific cases from which we gain a broad perspective about the effectiveness of federal actions under a range of circumstances.

It is clear that the federal government has in fact played a role in producing technical change in almost every industrial sector. Direct R&D support has been one instrument, as in semiconductors, but indirect instruments have played a larger part. Procurement associated with R&D support has been a powerful force in aircraft and computers. Regulations have influenced the pace and direction of change in automobiles, housing, and pharmaceuticals. Each industry has to be studied carefully to understand the sources of technical change. The converse, of course, is that government actions intended to bring about technical change should be tailored to each specific sector.

A number of experimental initiatives were attempted by the federal government during the middle and late 1970s. These were intended to stimulate technical change and innovation in the private sector. We look at several of them in this study as possible sources of lessons for the future.

Two of these -- CARP (Cooperative Automotive Research Program) and COGENT (Cooperative Generic Technology) -- failed to take hold. This, we believe, is clearly bound up with their failures to develop adequate political constituencies. The initiatives did not come from industry; they did not represent what industry thought to be the highest-priority problems in basic science or generic technology; and they did not necessarily represent the optimum allocation of available technical resources.

At the other extreme, a program to encourage joint university-industry research initiated by the National Science Foundation has had moderate success. It is an effort to expose universities to the scientific needs of industry, and to stimulate better working relations between the two sectors. Not every industrial research organization chooses to become a partner, but enough have done so to augur well for continuation at a reasonable level.

An industrial energy conservation program in the Department of Energy has demonstrated modest benefits for both public objectives (saving energy) and private benefits (reducing costs). Results were reasonable, though not dramatic, and the program demonstrated an incremental approach: the private benefits did not justify the total R&D investment required, but the anticipated public benefits could be obtained by adding funds of the federal government to the private funds.

Many themes emerge from the materials and analyses used for this study. A number are discussed in detail in Chapter V.

One obvious and pervasive theme is the need to achieve proper and constructive linkages between the federal agencies and the industrial community. The conversion of technical advances to new products, processes, and services occurs within the private sector. Decisions about investment, manufacturing, and distribution are made in the private sector. Thus, federal programs to support civilian-sector R&D require private inputs for planning and setting priorities, and must obtain participation in some form to smooth the conduct of R&D and the ultimate transfer to use. Clearly, a preferred situation is for the private sector to identify a desired federal activity in advance, something that was demonstrably lacking in the CARP and COGENT programs.

There is widespread agreement that the primary federal role in civilian R&D is to strengthen the technical infrastructure -- training, basic research, and generic technologies. Here, too, the specific mechanisms are important. Universities play the major third-party role between federal funding and eventual civilian-sector use. Appropriate linkages with the private sector are critical to be sure that the universities are aware of the basic scientific and engineering needs of industry; to encourage industry adaptation of university research; and to provide exposure of graduates to career opportunities.

A principal factor in the successful pursuit and eventual use of any technical advance is the existence of a technical community possessing the range of knowledge and skills needed to implement that advance. Federal programs, which can develop all needed skills in public-sector missions, cannot control this availability for programs in the civilian sector. Further, private sector involvement is needed to provide judgments on feasibility and timeliness of technologies potentially available for economic conversion.

Indirect actions of the federal government can have considerable influence on technical change -- regulations, tax policies, and, particularly, procurement. Thus, federal R&D programs of an applied nature can be most effective when coupled with some specific federal mission. In public-sector areas -- e.g., defense and space, in which the government is the customer -- federal applied R&D has been extremely successful. There is some indication that this combination can also work to various extents in areas where the government is not the principal user, such as solar energy, electronics, and agriculture. As the case of federal involvement in synthetic fuels suggests, of course, such federal procurement-cum-R&D is not therefore automatically desirable.

An important side-interest in this study is the by-product effect in many industry sectors of public-sector R&D. There continues to be disappointment and over-expectation about direct "spin-off," i.e., the easy conversion of products and processes developed for defense or space objectives into economic civilian use. But there has probably been an under-estimation of the broad economic value of the stronger base of science and technology this public research provided -- a base that has helped generate new industries, expand existing ones, and contribute to increased productivity generally.

A major trend that should be encouraged is the increased willingness and ability of particular industries to act collectively to strengthen their scientific and technological base. This has been shown in recent efforts of the electric power, gas, and other industries. It is also being shown in new initiatives by the chemical and semiconductor industries. To date, these efforts have focused on basic research, and may thus have considerable influence on related programs of the federal government in university research. These actions are in strict conformance with anti-trust laws. Our growing concern with international competitiveness may lead to opportunities for collective action in more applied areas. Such initiatives call for consideration of possible modification of anti-trust law and policy.

Suggested Criteria for Future Policy

The following is a distillation of our findings. We hope these points can serve as, broadly speaking, a set of guidelines for future policy toward civilian-sector R&D.

Nature of Contents

* Federal support for technical activities intended for the civilian sector, whether direct or indirect, should be specific to the industrial sector in question.

* The principal emphasis of federal support for civilian-sector R&D should go towards strengthening the technical infrastructure and encouraging generic science and technology, but with careful attention to those methods of implementation most compatible with needs of the civilian technical community.

* Federal procurement of goods and services (and sometimes other federal actions) justified by a mandate and supported by a constituency can often have salutary effects on civilian technology when such procurement is linked to federal R&D on the technologies or products being bought.

* A balance of technical resources should be maintained by providing a level of federal support for undirected basic research adequate to ensure objectivity and independence of direction in the research community.

* Federal support for applied research and directed basic research should be guided by specific arguments about particular technologies and types of projects "undersupported" by the private sector -- not by general arguments about the overall inadequacy of private R&D spending. And any proposals for programs to intervene in civilian-sector R&D should have a clear and specific institutional structure in mind to allocate the research dollars.

Nature of Mechanisms

* Cooperative R&D programs initiated and conducted by industry should be encouraged by both direct and indirect support of appropriate federal agencies.

* Federal support for directed basic research intended for the civilian sector should include specific mechanisms for linkages between industry and any third-party institutions conducting such research, whether government or academic.

* Federal support for applied research intended for the civilian sector should include specific mechanisms to obtain industry inputs, cooperation, and, where appropriate, participation.

* Federal actions in the civilian sector should flow from private initiatives whenever possible: mechanisms should be developed to encourage private sector initiatives in identifying technical needs, recommending appropriate roles for government relative to those needs, and in suggesting techniques for transfer of the results.

* Public sector R&D, e.g., defense and space, should be conducted so as to encourage linkages with the civilian sector in areas of basic science and generic technologies, when appropriate, during the planning and conduct of research.

* Linkages among university-industry-government programs should be promoted to strengthen the general technical infrastructure, improve the flow of information concerning technical advances and needs, and expedite transfer of such advances.

I. THE CHANGING TIDE.

In 1971, President Nixon assigned Mr. William M. Magruder, an experienced aerospace executive, the task of developing a list of major technical activities, to be supported in some degree by the federal government, which would serve to utilize available technical manpower and knowledge in programs that could support and stimulate economic growth. This was referred to as the New Technology Opportunities Program (NTOP).

In hindsight, this initiative appears as a tangible divider between two eras in federal R&D policy. From 1940 to 1970, federal support of R&D was growing; but that support was directed largely toward defense, atomic energy and space -- areas in which the government was itself the final customer for the R&D and the new technologies it produced. Other sectors benefited through "spin-offs." After 1970, however, federal R&D support was used increasingly as a way of supporting and stimulating the general economy -- in areas such as transportation, housing, communication, and energy.

Mr. Magruder's assignment came at a time of slow-down in the military R&D spending, so that unemployment among certain high-technology personnel, notably aerospace engineers, became an unwelcome new phenomenon in the United States. Concurrently, an economic recession in the early 1970s focused attention on industrial needs and on mechanisms that might revive a lagging economy. An approach that would appear to address both problems had obvious appeal. But while the dimly perceived issues of both policy and practice were slowly being formulated and discussed, the economy revived, technical specialists were absorbed (possibly involving conversion of skills) and the plan for major government involvement in support of civilian-sector R&D was filed away.

From this first aborted step contemplating broad action, there followed a growing series of specific federal programs, each motivated by some particular problem concerning an industry sector -- e.g., energy or automotive -- or an element in our general industrial base -- e.g., materials availability or adequate long-range research. By the late 1970s, federal agencies were conducting a wide range of activities, and there were new legislative proposals to add more.

Like all questions of public policy, analzying the role and effectiveness of government involvement in civilian-sector R&D cannot be accomplished in an intellectual or political vacuum. Such an analysis must necessarily start with the premises -- often unarticulated -- that accompany the political and institutional structures it assumes.

Until very recently, the premises upon which government policy toward civilian-sector R&D rested were developing in a fairly clear and seemingly constant direction: greater government involvement.

One indication of this tendency is apparent from the numbers. In constant 1972 dollars, federal R&D spending on defense declined from $11.9 billion to $8.5 billion between the years 1967 to 1980, while the component devoted to civilian-sector interests rose over that same period from $4.9 billion to $7.2 billion.[1] But the trend is not merely quantitative. Government involvement in civilian R&D changed in character,

1. Willis H. Shapley and Don I. Phillips, Research and Development: AAAS Report IV, Washington, D.C.: American Association for the Advancement of Science, 1979, p.26, and Shapley, et. al., Research and Development: AAAS Report VI, Washington, D.C.: American Association for the Advancement of Science, 1981, p. 17.

moving from a regime in which the support of basic research and the molding of technological infrastructure was itself the goal to one in which the support of R&D was an announced <u>means</u> to various social goals -- notably the goal of technological supericrity in international trade. As such, this conception of federal R&D policy toward the civilian sector was only one manifestation of what all political persuasions agree to have been an increasingly interventionist development of general government after World War II.

This is not to say that the altered and enlarged federal role in R&D evolved smoothly or without incident; in fact, as we will try to document below, the premises of federal R&D policy reigning in October, 1980, were the legacy of a very episodic history. Technology policy in the last few decades was shaped by at least three periods of policy activism which, although failures politically, were ultimately victories intellectually -- at least in the sense that until recently they set the tone for Executive Branch policy.

This study was commissioned and begun during the last of the activist periods, that of the departed Carter Administration. As a result, the study started out from what we might call a "pragmatic" base. Given the increasing government support of civilian-sector R&D, we asked, what criteria should the policy-maker use to extract optimum effectiveness from the various government R&D programs?

There were two sources of material from which to develop such criteria. First, there is historical experience in each industry relevant to understanding the sources of technical change; the conditions for its introduction and use; and the impact of federal policies upon it. In our view, it is important to recognize that each industry is unique in its needs and conditions -- a fact far too often overlooked in discussions of federal civilian-sector R&D policies. Therefore, there is much to be gained by a review and analysis of the factors influencing technical change in each of a number of industries differing in, for example, their R&D intensity and the degree of federally funded R&D.

Second, the expanding federal R&D activity in the past ten years that was intended to support or stimulate specific industrial sectors has given rise to considerable empirical data and experiences, viz., (a) new program initiatives put forward by the government to explore various mechanisms for interactions with industry -- e.g., the Cooperative Automotive Research Program (CARP) -- and (b) a group of government and industry executives who have devoted increasing amounts of time to working with these mechanisms and with each other, taking into account the combined government-industry technical efforts in planning their own activities for creating technical change. Discussions with these executives about the effectiveness of both the newer exploratory programs and the older, established programs could provide a rich base of judgments on the role and workability of federal R&D support.

The material for this study did indeed draw upon these two principal sources, and this report is based primarily on them, on other published references, and on the judgments and interpretations of the authors. A group of knowledgeable economists has prepared a set of studies on the history of technical change in seven major industries affected in varying degree by federal actions. An overview of these analyses is presented in Chapter III, and the complete set is appearing as a separate publication. These provide references and perspectives for much of this present report. Chapter IV describes, categorizes, and analyzes several of the new initiatives proposed during the Carter term.

We also did in fact interview and meet with many industry and government officials both individually and at several special seminars.

But, although this study has its roots in the ground of the last administration, its fruit ripened in the climate of the present administration. This has influenced in a critical way the questions and emphases that govern the conclusions of this study.

There is a strong case to be made that the last few months have seen the beginning of a reversal in the post-war trend in federal policy toward civilian-sector R&D. To put it somewhat crudely, the first question raised nowadays is: is there any appropriate role for direct federal R&D support in the area under consideration? Only when and if the answer is "yes" does a concern with the "what" and "how" arise.

This changing tide affects the emphasis of this study, even though it arrives during the last third of the time allocated. Discussions with government and industry executives brought out sharply the increasing priority on philosophy -- on the question of "why?" -- that has lately replaced the earlier question of "how?"

All of this, of course, required considerable attention by the authors to the reordering and re-evaluation of the material already in hand. For example, government initiatives that were studied as possible examples of future growth now become historical examples of largely intellectual interest.

But this shifting of premises is not so much a problem for the study as it is a challenge and an opportunity. With one foot in each of two very different realms, we perhaps gain a perspective that is not confined by any particular set of narrow premises. At the very least, the study offers an element of continuity in a time of change, and should therefore provide a useful bridge between past and future science and technology policy.

II. R&D POLICIES IN PERSPECTIVE.

In order to fill in some of the vacuum that normally surrounds discussions of federal R&D policy, this chapter attempts to place the relevant issues in a proper (a) historical, (b) practical, and (c) tneoretical context.

We need to begin with some definitions.

1. The participation of the government in an area of technical activity can be active or passive with regard to its role in directing the allocation of technical resources towards specific ends. Thus, government support for the general scientific and technical base of the country -- the programs of the National Bureau of Standards, the basic research objectives of the National Science Foundation, fellowship grants for university study -- can be considered passive. An example of an active intervention, by contrast, might be the government commitment to titanium development, dating from the late 1940s, that specifically sought the development of light-weight metals for military aircraft. (The term "active" is not intended to describe the physical intensity of the R&D effort, but rather to distinguish the specificity and goal-directedness of the government involvement.)

2. The mechanisms used by the federal government to influence civilian-sector R&D may be direct or indirect. The specific allocation of money to fund a desired technical program like solar cells, whether in government laboratories or by outside contracts, is direct R&D support. The provision of tax credits for the installation of solar collectors

is an indirect mechanism to stimulate a market for such devices, and thereby to create incentives for private R&D efforts. The former method specifies the conduct of an R&D program approved by the government; the latter provides incentives for moving in a certain direction, but does not mandate R&D or specify its type or extent. Other indirect mechanisms would include general tax and subsidy policies, tariffs, regulation -- both economic regulation and the newer "social" regulation -- and even macroeconomic policies.

A. Historical Perspective.

In the 19th and early 20th centuries, the direct efforts of the federal government in civilian R&D were fundamentally passive.

A patent system was specified in the U.S. Constitution and the Patent Office was the earliest federal presence in R&D. Indeed, it is the Patent Office that was largely responsible, in 1839, for originating the most significant direct federal efforts of the 19th century: agricultural research. By 1860, several states had already established agricultural colleges; and 1862 saw the establishment of the Agriculture Department as well as the Land Grant College Act, which provided funds for agricultural colleges in every state. These early educational efforts were focused on practical training far more than on research; but the Hatch Act of 1887 provided each state with funds specifically for research.[1]

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1. See Robert Evenson, "Technical Change in U.S. Agriculture," in R.R. Nelson, ed., Technical Change in U.S. Industry: A Cross-Industry Analysis, New York: Center for Science and Technology Policy, 1981. [Hereinafter cited as Nelson (1981)]. As noted above, this companion volume to the present report contains detailed analyses of technical change in seven major areas of U.S. industry. The study's conclusions are summarized more fully below in Chapter III.

Federal funding of agriculture could be considered active in the limited sense that such research was seen as a means for spurring improvement in a particular industrial sector. Yet, these efforts were entirely passive in the sense that the federal government did not -- and still does not -- have a strong influence on the direction of the research or the selection of projects.[2]

Another passive government aid to science and technology was the creation of the National Bureau of Standards. Begun in 1901 as the successor to the Office of Weights and Measures, the NBS before World War II largely confined itself to setting standards and conducting research directly related to standards and measurement.[3]

In the 20th century, the most characteristic influence of federal action on civilian R&D has been the "spin-off" effect from non-civilian -- usually military -- federal research. A good example of this is the commercial aircraft industry, where developments in airframes and (especially) engines for military aircraft found direct application in civilian aviation. The National Advisory Committee on Aviation (NACA -- the forerunner of present-day NASA) was set up in 1915 with explicitly military goals -- although, until about 1935, its laboratories provided important empirical and technological information that was as useful in civilian applications as in military.[4]

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2. Evenson, Op. Cit.

3. See Weights and Measures Administration, National Bureau of Standards Handbook, 82, U.S. Department of Commerce, 1962.

4. David Mowery and Nathan Rosenberg, "Government Policy and Innovation in the Commercial Aircraft Industry, 1925-75," in Nelson (1981), Op. Cit.

This pattern of influence was not unique to aviation; much the same story can be told about such industries as computers and semiconductors by merely translating a few decades forward in time.[5] In other areas, though, industrial development was influenced only negligibly by direct federal R&D efforts, whether spun-off or otherwise.

In such areas as railroads, automobiles and housing, the extent and direction of technical change was influenced solely by indirect federal actions until the 1960s. In the case of automobiles, for example, federal tax policy and the subsidization of a massive highway system -- not federal R&D -- shaped the modern American car.

It is only after World War II -- and, for the most part, not until the 1960s -- that we begin to find government involvement in civilian-sector R&D that is both direct and active.

The period in U.S. history from 1945 through the 1960s (and beyond) was characterized by a number of generally agreed-upon attributes. Politically, there was a slowly decreasing resistance to the enlargement of government and to its extension into the civilian sphere. Furthermore, public attitudes toward science and technology were extremely favorable, with widespread confidence in the ability of those disciplines to solve problems and produce results. Public anxiety had other causes; a growing recognition of U.S. preeminence in world affairs, coupled with the sentiments and intuitions of the cold war, led to an attitude of "gappism" that called out in alarm whenever the U.S. was seen to be "lagging" in aggregate statistics of one kind or another.

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5. See Barbara Katz and Almarin Phillips, "Government Technological Opportunities, and the Structure of the Computer Industry, 1946-61," as well as Richard Levin, "The Government and Technical Change in the Semiconductor Industry," in Nelson (1981), Op. Cit.

It is probably not too surprising that these factors should have combined to yield programs to use government-funded R&D as a "control variable" to effect national civilian objectives -- notably the prevention or elimination of a "technology gap" relative to other developed countries. By 1980, the desirability of such programs was virtually a given in national science and technology policy.

This is not to say that this opinion was or is unanimous or that its dominance in policy circles came gradually and uneventfully. In fact, the premises of science policy reigning in Washington at the time this study began were the product of at least three distinct and identifiable periods of government activism.

The first of these periods came in the early years of the Kennedy administration -- a time when, in the view of many scholars, the governing attitude in the White House was that public policy is no longer a matter of ideology but of dispassionate technocratic management.[6] The Commerce Department created the post of assistant secretary for science and technology; and J. Herbert Hollomon, then head of GE's Engineering Laboratory, was named to fill it.

Hollomon's major project was to initiate a Civilian Industrial Technology Program (CIT). The program would have (a) provided funds for university personnel to work on industrial research; (b) attempted to stimulate industry to undertake more risky or expensive R&D; (c) developed an Agriculture-like university-industry extension service; and (d) provided services for collecting and disseminating technical information.[7]

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6. See, e.g., Arthur Schlesinger, A Thousand Days, 1965, p. 644.

7. D.S. Greenberg, "Civilian Technology: Concern Over Pace of Growth Inspires Program for Research and Development Effort," Science, Vol. 139, February 5, 1963, p. 576.

The *raison d'être* of CIT was the perceived "gap" in industrial technology, apparently measured not by a comparison of technological outputs but the proportion of inputs devoted to civilian technology relative to other industrialized countries.[8] Hollomon saw many U.S. industries as "lagging" in the application of science and technology to production, a view he expressed with what the science press of the day termed a singular lack of diplomacy.[9] Industry officials, with the help of labor, quickly succeeded in killing the program.[10] Congress eventually approved the "extension service" part -- and then killed even that in 1969.[11]

The idea of an industrial R&D effort lay dormant during the Johnson years, although spending on non-military R&D rose as the line agencies of the Great Society channeled resources into areas like health, education and housing. The Nixon administration initially displayed a lack of enthusiasm for an industrial technology program; indeed, the incumbent successor to Hollomon as assistant Commerce secretary resigned in quiet despair over the administration's technology efforts.[12]

But, within a matter of months, the winds shifted. Partly because the economy, overheated by budget deficits and monetary inflation during the Vietnam War, was beginning to

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8. Ibid.

9. D.S. Greenberg, "Civilian Technology: Program to Boost Industrial Research Heavily Slashed in House," Science Vol. 140, June 28, 1963, p. 1380.

10. D.S. Greenberg, "Civilian Technology: Opposition in Congress and Industry Leads to Major Realignment of Program," Science, Vol. 143, February 14, 1964, p. 660.

11. Andrew Hamilton, "State Technical Services Act: Congress Swings the Axe," Science, Vol. 166, December 26, 1968, p. 1606.

12. John Walsh, "Myron Tribus, Top Science Official, Resigns," Science, Vol. 170, December 4, 1970, p. 1065.

turn down, and partly because the imminent end of the Apollo program was creating unemployment in the science and engineering community,[13] the Nixon administration, as part of its economic policy, suddenly became very interested in fostering industrial technology.[14]

This time, the initiative came not at the assistant-secretary level but at the level of the White House staff. Nixon brought in William Magruder -- fresh from heading the administration's ill-fated SST effort -- to organize the New Technology Opportunities Program (NTOP),[15] a four-month executive-branch policy study completed in January, 1972.

As a practical matter, this initatives program got little further than its predecessor in the 1960s. There was initially much talk about tax incentives for private R&D; large increases in federal spending for applied civilian research; changes in the anti-trust laws; and even a reorganization on the federal R&D policy and management organization.[16]

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13. Initially, the administration's position had been that it would not try to stimulate R&D as a way of reducing unemployment among technologists, relying instead on special retraining and information programs. See Philip M. Boffey, "Unemployment: What Nixon Is/Isn't Doing to Help Jobless Scientists," Science, Vol. 171, March 12, 1971, p. 985.

14. Nicholas Wade, "Nixon's New Economic Policy: Hints of a Resurgence for R&D," Science, Vol. 173, August 27, 1971, p. 794. On the New Economic Policy generally, see Herbert Stein, "Remembering the Fifteenth of August," The Wall Street Journal, August 14, 1981.

15. Deborah Shapley, "Magruder in the White House: SST Man Plans New Technology Take Off," Science, Vol. 174, October 22, 1971, p. 386.

16. See Claude E. Barfield, "High-Technology Package Focuses on Domestic Needs, U.S. Trade Balance," National Journal, October 23, 1971, p. 2114; Claude E. Barfield, "High-Technology Research Program May include Tax and Antitrust Proposals," National Journal, October 31, 1971, p.2156; and Deborah Shapley, "Technology Initiatives: Hints on the Magruder Effort," Science, Vol. 175, January 21, 1972, p. 279.

There was also considerable effort put into the preparation of plans for major civilian-oriented R&D programs. But when the program reached Congress, it contained only modest increases in spending on goal-directed research for social concerns and a $40 million cooperative program under which the National Science Foundation and the National Bureau of Standards would jointly "test incentives to stimulate R&D."[17] These funds were promptly impounded by the Office of Management and Budget (OMB).[18]

On another level, though, the Magruder effort was a success. For it signalled the ideological victory within a Republican administration of the proposition that civilian-sector R&D is a lever that, in the hands of the government, can affect the macroeconomic problems of productivity and international trade. No less a figure than then-Commerce secretary Maurice Stans testified before Congress to the administration's faith in this proposition.

The candor with which Stans presented the case is almost startling. He cited figures -- based, evidently, on the neo-mercantilist analyses of an enterprising Commerce economist[20]--

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17. Fred H. Zerkel, "White House Shapes Strategic Approach to R&D," Chemical and Engineering News March 20, 1972, p. 24.

18. Robert Gillette, "Technological Initiatives: NBS Funds in Holding Pattern," Science, Vol. 179, Jan. 12,1973, p. 163.

19. Maurice Stans, "Science, Technology and the Economy," Statement before the House Subcommittee on Science, Research and Development, July 27, 1971, reprinted in NBS Technical News Bulletin, November 1971, p. 270.

20. See Phillip M. Boffey, "Technology and World Trade: Is There Cause for Alarm?" Science, Vol. 172, April 2, 1971, p. 37, and Deborah Shapley, "Technology and Trade Crisis: Salvation Through a New Policy," Science, Vol. 179, March 2, 1973, p. 881. The concern with a "trade gap" was also voiced in the popular press. See "Making U.S. Technology More Competitive," Business Week, Jan. 15, 1972, p. 44. For a more balanced contemporary view, see Harvey Brooks, "What's Happening to the U.S. Lead in Technology?" Harvard Business Review, Vol. 50, No. 3, May-June 1972, p. 110.

linking an unfavorable trade balance with inadequate spending on civilian R&D. Then, listing all the other factors conventionally thought to govern a nation's trade position -- inflation, exchange rates, tariffs, quotas, etc. -- Stans argued that the only variable the government could really control is "technological development" (read: civilian R&D). "(T)he major element which we can influence decisively for the long-run," he told the House Science, Research and Development Subcommittee, "is the level of technological development. It may be our only hope of maintaining a future trade position adequate to support our balance of payments in the years to come."[21] The only dissent seemed to come from that perennial spoil-sport, OMB.[22]

Watergate and its aftermath put the question of civilian R&D initiatives on the back burner at top administrative levels. Only at the lower echelons of the civilian agencies did the pot continue to simmer.

In May, 1978, President Carter called for a domestic policy review (DPR) on innovation. This review, completed in 1979 under the direction of Jordan Baruch, the most recent assistant Commerce secretary for science and technology, produced a more specific and more ambitious set of proposals than did its predecessors. Analyzing this third initiative and its proposals is the topic of Chapter IV below.

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21. Stans, Op. Cit.
22. Wade (August 27, 1971), Op. Cit. p. 795.

B. Functions and Role of Industrial Research.

In order to understand the significance of the Carter initiatives, though, more than a historical background is necessary. One also needs a background on the principles and procedures by which science and technology relate to civilian objectives. In particular, one needs to know something about industrial research and how it operates.[23]

The activity in society likely to be most important to an effective federal role in civilian-sector R&D is industrial research itself. The industrial research sector is the principal instrument for integrating science and technology into the U.S. industrial system, which in turn is the instrument by which the resulting products, processes and services are introduced into the economy.

Thus, the effectiveness of federal efforts intended to support civilian-sector R&D depends very critically on interactions with industrial research. It is at the least a vital part of the transfer process between any federal program and the ultimate user, and it can be a major source of inputs and assistance for such programs.

The evaluation of past federal actions and suggestions for future guidelines call for some comprehension of the principal functions of industrial research and how these are carried out. Without in any way attempting to describe the history of industrial research, this section will set forth simply those specific aspects which must be understood and considered in the development and implementation of a national

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23. For a fuller treatment in a slightly different context, see Herbert I. Fusfeld, Perspectives on U.S. Industrial Innovation, New York: Center for Science and Technology Policy, January, 1981. This publication also contains an annotated bibliography by Theodore W. Schlie, of which see especially pp. 7-13.

science policy. This rests to some extent on understanding the role of the private sector itself.

The characteristics of the private sector relevant to our discussion are:

1. It decentralizes decision-making. Each individual firm makes decisions on the allocation of those resources within its control.

2. Each firm tries to allocate its resources so as to produce maximum return on investment consistent with long-term growth and stability.

3. The profit motive (or profit constraint) creates an internal pressure within each firm to maintain a proper balance among its resources.

Now, consider the role and characteristics of industrial research in this environment. It is not an independent activity, set apart, feeding occasional ideas and technical breakthroughs along a one-way communication link to an eager and waiting production line. It is, and must be, very much a part of the whole industrial system. Thus, the firm has to make plans for:

1. Technical programs and/or areas relevant to the business strategy of the firm;

2. The level of technical effort compatible with the needs and abilities of the firm; and

3. Mechanisms for conversion to use of successful R&D programs.

The key to all these activities is balance. This is both qualitative, as in the case of business strategy and management capabilities, and quantitative, as in the use of available funds and manpower in light of probable return. The process by which one arrives at these judgments must consider the cost and technical feasibility of adapting successful R&D to workable manufacturing processes using economically available materials to give satisfactory performance in use.

There are, in short, certain disciplines that make up industrial research. This is why otherwise identical technical projects concerned with (say) removing sulphur from coal would have fundamentally different attributes when conducted by an industry, a university, or a government environment. Among these attributes are:

1. Consideration of the system which will be used to develop manufacturing processes and arrange distribution.

2. Consideration of all technical characteristics of a final product or process as defined by the needs and constraints of the user.

3. Consideration of the interactions among market demands, cost, investment, and technical performance of the product or process.

4. Consideraton of perceived options to meet the broad needs of the potential user with regard to a specific mission-oriented objective, either through competitive technical approaches, substitutes, or non-technical approaches (e.g., use of economic incentives or penalties).

The industrial research community, particularly the research manager, is the bridge between science and the user and must account for the transfer process between the two. The research manager is aware that the function of R&D is to provide options -- for solutions to problems or for investments -- that are acceptable economically to society. The R&D activities are integrated with a complete manufacturing and distribution system, and all parts of the system are involved in the earliest planning and the ultimate use.

These are, of course, precisely the approaches required to answer the questions raised regarding an active science policy in the civilian sector: how to decide on priorities among technical programs and how to provide for effective transfer. The mechanisms for both reside within industrial research. The problem is how to couple this know-how with government programs.

Those federal policies that recognize and make use of the characteristics of industrial research will be most likely to improve the effectiveness of civilian-sector R&D. Those that do not, either through lack of understanding of those mechanisms or because of the pressure of other national objectives, will lower this effectiveness.

These comments are valid for the range of federal interactions with the private sector in the R&D field. These include the direct efforts where federal funding may support R&D conducted within industry, or where some form of cooperative efforts between government and industry is the mechanism. It obviously holds for such indirect effort as tax incentives. In any instance, the unique aspect of industrial research is the integration of the R&D organization with the other resources of each individual corporation, not simply the R&D capability as an isolated resource.

This summary of the nature of industrial research can be made more complete for the purposes of this study by adding a few comments about specific operating characteristics. The most important feature is that each industry is unique with regard to such factors as:

* Whether competition is atomistic or rivalrous;
* The sizes and size-distribution of firms;
* The ease of entry for new firms;
* The R&D policies of the firms;
* The nature of the customers and their innovative behavior;
* The proprietary characteristics of the knowledge produced by R&D in the industry; and
* The nature and extent of government regulation.

There are others. What comes through sharply in this list is that the reaction of industry to any federal effort in R&D will be different for each industry -- indeed for each company.

Thus, there is considerable variation among industries in the linkages with, and dependence upon, outside sources of technical change. These diverse links include cooperative plans with universities, joint ventures with other companies, liaison activities with technical organizations internationally.

In the broadest sense, then, there are several principles concerning federal support of civilian-sector R&D that emerge from considerations of industrial research:

* First, the effectiveness of a program will be related to the extent of "tailoring" to the characteristics of the industry or industries affected.
* Second, there must be a clear appreciation of the strategic planning taking place in each industry for the integration of technical change in its economic growth.
* Third, the value of direct vs. indirect federal actions is dependent upon each industry.

C. R&D and Productivity Growth, and the Roles of Public R&D Funding.

Economic analyses sometimes lead, and sometimes lag, policy deliberations. In the case of government policy toward industrial innovation, economic analysis ran ahead of general policy discussions.

During the 1960s, there was considerable support within the professional economic community for the proposition that government ought to play an active role in industrial innovation. That support rested on two separate lines of analysis. First, several studies during the 1950s led economists to believe that technological advance accounted for the lion's share of the high productivity growth then being experienced, and that research and development expenditures were an important source of technological advance. Second, a variety of theoretical arguments suggested that, in general, profit maximizing activity by business firms operating in competitive markets leads to a level of spending less than the "social optimum."

In recent years, economists have learned that the relationships between R&D and productivity growth -- and the kinds of roles that government fruitfully can play in industrial innovation -- are more subtle and complex than these earlier formulations had indicated. But the development of these earlier theories strongly influenced the direction of policy; and the intellectual history of those analyses is directly relevant to understanding the history of government policy toward civilian-sector R&D.[24]

There has been a long tradition in economics of research on productivity growth. Adam Smith was interested in that topic, and he assigned much of the credit for the rapid productivity growth then occurring in England to what now would be called industrial innovation. He noted several sources of innovation, including what we would now call "learning curves," and he recognized the background role of basic science. Many economists since Smith have speculated on

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24. For a comprehensive review of earlier scholarly thinking on R&D and innovation, see Richard R. Nelson, Merton Peck, and Edward Kalachek, Technology, Economic Growth and Public Policy, Washington, D.C.: The Brookings Institution, 1967. For a more recent viewpoint (by one of the same authors) on the economics of innovation and R&D, see Nelson and Sidney Winter, "In Search of a Useful Theory of Innovation," Research Policy, Vol. 6, (1977), p. 36.

the sources of productivity growth and industrial innovation. In the 1950s, economists at the National Bureau of Economic Research began systematic studies to identify the sources of experienced productivity growth. As a result of their work (and that of Robert Solow and Edward Denison) economists, by 1960, were in accord that only a small fraction of the growth of output per worker experienced in the United States could be attributed simply to increases in machinery or other material inputs per worker. Most of the productivity advance showed up as a disembodied increase in the capability to produce goods and services from given inputs; the country's economists associated this increase with technological advance. During the early and middle 1960s, many scholars noted that the technological advance, measured as an increase of the productivity of all inputs, seemed to have accelerated significantly in the post-war years. It was recognized that R&D spending had increased greatly as well, and many scholars drew the obvious connections.

At roughly the same time, a number of scholars were inquiring into the determinants of R&D spending by business firms and exploring, within the context of various models, whether the magnitude and allocation of R&D spending most profitable for business firms is also "optimal" from a social point of view. The results of these inquiries led economists to argue that a more active government role in stimulating industrial R&D would be in the social interest. There were several arguments in the economists' quiver. First, it was argued, R&D expenditures often yield "externalities": the returns to one firm's R&D flow in part to other parties and are therefore only partially capturable by the firm that bears the R&D expense. A second argument was that efforts to achieve significant technological breakthroughs inevitably involve considerable uncertainty; when uncertainties are very large, business investment is likely to be deterred even if the expected gain is reasonably high. Both of these arguments suggested that, when judged from a social point of view, private investment in R&D is necessarily insufficient; and this pointed toward federal policies to supplement private R&D spending. It seemed plausible that federal funds should go into the kinds of R&D and the industries where the externalities and uncertainties were greatest. In addition, many economists were arguing, when industry structure is fragmented, the firms tend to be too small to mount an efficient R&D effort. Special federal programs for such industries ought to be considered.

These theoretical arguments were supported by a few quantitative studies of the social returns to particular R&D investments. These studies showed such returns to be very high. Studies of federal R&D support, particularly in agriculture, showed past government involvements to have been excellent social investments.

Taken together, the economists' findings about the important role of technological advance in economic growth and their arguments about a tendency of private business firms to under-fund R&D provided strong intellectual support for those within -- and outside -- government who believed in a more active federal presence. The economists' arguments were presented in the 1962 annual Economic Report of the President in support of the then-developing civilian industrial technology program (CIT) mentioned earlier. They have also been used, in one way or another, in all later discussions about the appropriate government role.

Economists now understand that the relationships between R&D spending and productivity growth are more complicated than they earlier believed. During both the Magruder exercise and the more recent Domestic Policy Review on innovation,[25]

25. Cf. Chapter II.A. above.

the erosion in the American technological lead was a topic of considerable concern. Government stimulus of R&D was put forth as a means to halt the relative decline. However, a number of recent studies have shown that the differences among the industrialized nations in their rates of productivity growth are not well correlated with their R&D spending, either in volume or as a function of GNP. Indeed, the two countries which in the 1950s and early 1960s had the highest ratio of R&D to GNP -- the United States and Great Britain -- experienced among the lowest productivity growth rates. It has been noted that both the U.S. and Britain allocated an unusually large share of their R&D to defense purposes. In any case, productivity growth among nations has been much better correlated with physical investment as a fraction of GNP than with R&D as a fraction of GNP, whether defense R&D is counted or not.

Once one recognizes the relative ease with which technological knowledge flows across national boundaries, this conclusion should not be particularly surprising. Certainly in the 1950s and 1960s, the European countries and Japan were benefiting greatly from their ability to adopt technology developed or employed earlier in the United States. There is evidence (for example in the form of patent licensing statistics) that, as technological levels among countries have come closer together in the 1970s, the United States is beginning to benefit from technology developed in other countries.

This suggests a more subtle connection between a country's overall R&D effort and its relative productivity growth performance. So long as their physical investment rates are substantial, countries with productivity levels and technologies well below the frontier can probably achieve rapid productivity growth even if their R&D spending is modest.

A country's R&D effort becomes more important when it is close to or striving toward the frontier, or trying to hold a position at the frontier. For countries in this position, a strong R&D effort is necessary for rapid productivity growth, even though it may not be sufficient.

Just as differences in countries' productivity growth rates have not been strongly correlated with differences in their R&D spending, variations in a country's economic growth rate over time are not well associated with variations in its overall R&D spending rate. In particular, it is unlikely that the worsened productivity growth experienced in most countries after 1973 was caused by a fall in their R&D spending. What is true is that the surge of productivity growth that the United States, Western Europe, and Japan enjoyed during the 1960s came at a time when, by historical standards, all of these countries were investing heavily in R&D. But the slowdown of productivity growth since 1973 has been ubiquitous. Only in the United States and France was the productivity growth deceleration foreshadowed by any slowdown in R&D expenditure. And in those countries, the bulk of that R&D decline has been in government R&D spending on defense and space -- not in industrial R&D spending on industrial innovation.

Again, a more subtle analysis seems called for. Even for a country close to the frontiers of technology, it will take time before variations in R&D spending affect productivity growth; and it matters what kind of R&D spending is advancing or declining. Nonetheless, it probably is true that a country cannot long stay at the forefront if it allows the level of its industrial R&D focused on new products and processes continually to erode.

The connections between R&D spending and productivity growth show up more sharply when one considers the differences in measured rates of productivity growth and technical advance among sectors and industries. Almost invariably, industries experiencing rapid productivity growth either spend a considerable amount themselves on R&D or have equipment or material suppliers who spend a considerable amount on R&D. Those who spend little themselves on R&D, and who are not fortunate enough to have technologically progressive suppliers, have experienced very slow productivity growth. The question of why there are such great differences across industries and sectors in the R&D attention they are attracting is interesting, important, and at present not well answered. One possible answer is that R&D on the technologies in some industries is not very fruitful, and the lack of R&D attention simply reflects this. Another possible answer, consistent with the theoretical arguments that private firms spend too little on R&D, is that a variety of institutional factors render R&D privately unprofitable in circumstances in which it would be socially fruitful. And no government policies have yet been devised to remedy the situation.

The question is particularly germane to this report, since government programs in support of civilian applied R&D inevitably will -- and should -- differ from sector to sector. What makes sense for agriculture may make little sense for pharmaceuticals. Government policies to stimulate industrial innovation in general can make use of across-the-board instruments like the new tax credit for (increments to) R&D spending or various mechanisms to facilitate fruitful university-industry interaction. Support of academic basic research conducted at universities is also a general-purpose tool, even though its effects (as that of tax credits) are likely to vary significantly from industry to industry. When the focus is on direct support of R&D aimed at advancing technological understanding or capability, it is essential to recognize that particular programs inevitably will be targeted on particular industries or industry groups. What is appropriate for one industry may not be for another.

What are the appropriate roles for the federal government in stimulating and guiding applied R&D spending? In particular, what kind of R&D should the federal government itself finance? What industries and technologies especially warrant government R&D support? Economists once thought they knew the answers to these questions. But, as economists began to recognize more clearly the complexities of the relationships between R&D spending and productivity growth, the simple arguments that had once seemed to provide support and guidance for an active federal role in civilian-sector R&D began suddenly to unravel. The situation is now recognized to be more complicated -- and directions for policy to be more uncertain.

In the first place, when a competitive firm's inventions are protected to some degree by patents or secrecy, there are incentives for the firm to do R&D that, in effect, duplicates or "invents around" already available technology. Although "externalities" may lead firms to underinvest in R&D from a social point of view, these incentives to duplicate or "invent around" pull in the opposite direction. While it is still clear that the allocation of R&D resources generated in a competitive industry by profit incentives may not be "socially optimal," the problem is not easily characterized in terms of under-spending. Also, it is not obvious what, if anything, federal policy can do to improve the allocation of R&D spending, particularly when firms are reluctant to disclose their own R&D programs to public view.

Similarly, the implications of that considerable uncertainty which attends endeavors to advance a technology significantly now are understood to be far more complex and subtle than was once thought. Under conditions of technological uncertainty, the appropriate strategy from a social point of view would appear to involve the exploration of a number of different alternatives, rather than a "big push" in one direction or another. The aborted federal attempt to fund development of a supersonic transport illustrates the problem in paradigmatic fashion.

The argument that a federal role is particularly warranted in industries where firms are small also began to come apart. It was noticed that in some industries, technical progress was slow despite the fact that firms were large, and in some industries where technological progress was rapid, new and small firms were important sources of the key inventions. The experience with Operation Breakthrough vividly illustrated the dangers of applying the agriculture model indiscriminately. Even if the experience of agricultural policy is applicable to other industries with a similar, "fragmented" structure, the necessary institutional arrangements remain complex and hard-to-put-together in a political setting.

At the same time, analysts have also come more fully to realize that government-supported R&D associated with procurement, and government-funded research undertaken at universities but tailored to particular social needs or technologies, have contributed to civilian innovation in a number of industries. In considering government R&D support to spur industrial innovation, it may be a mistake not to consider very carefully procurement-related R&D and support of R&D at universities. The federal government has a choice about whether and the extent to which it funds R&D on the products it procures. Similarly, there is considerable room for discretion regarding the range of research topics that the government can support in a university setting with the research results treated as non-proprietary.

These considerations suggest some guidelines for the role of the federal government. We think it apparent that the R&D

allocation generated by market incentives is not necessarily "optimal." But federal policies to improve that allocation will have to be subtle, and formal theoretical reasoning does not take us very far toward understanding which kinds of policies will work. Thus, the question of appropriate federal policies is largely an empirical one, not a theoretical one. The research we have undertaken on the history of federal involvement in seven American industries -- reported below in Chapter III -- and on recent federal technical initiatives in the civilian sector -- discussed in Chapter IV -- is a start on such empirical research.

D. Perceptions of Government Action: Inputs from Executives in Government and Industry.

If, as we have suggested, understanding the process of technical change in industry -- and the involvement of government in that process -- is a rather subtle and complex institutional problem, then it becomes clear that any federal efforts in the service of civilian technology must recognize the institutional problem and work within its constraints.

In particular, the message of the foregoing sections is in large part that effective government R&D efforts in the civilian sector must understand and utilize effectively the knowledge and incentives of private industry. Furthermore, as history suggests, the political success of such a program depends crucially upon the development and maintenance of a constituency for its support.

This immediately implies that successful federal involvement in civilian R&D requires a non-confrontational interaction with industry -- that government support depends for its effectiveness on the understanding, cooperation, and involvement of the industrial research executives and senior government officials who must set policies and make decisions on technical programs.

With this in mind, it seemed to us essential to examine the views of decision-maker -- both in industry and in government -- who have been involved in public-private interactions in civilian-sector R&D. And an important aspect of this study thus has been to engage such individuals in discussion about the government role in civilian-sector R&D; about specific program initiatives; and about specific mechanisms for implementing government objectives. These discussions occurred partly in three workshops of about 20 to 25 people each, and partly in individual discussions. There were two principal purposes served.

First, these key personnel provided critical perspectives concerning the subjects examined in this study. These value-judgments and anecdotal experiences were helpful in the task of extracting lessons from the material assembled, and were undoubtedly responsible in large part for the generally pragmatic tone reflected throughout this report.

Second, the commentaries and perceptions of senior executives provided an important base for developing the general themes summarized in Chapter V and for suggesting the criteria to guide future policy actions. The accompanying industry studies, the recent government initiatives, and the historical evolution of public- and private-sector R&D offer a large number of specific examples of good and bad interactions; but the selection of simply stated criteria that might serve as a more general guide was aided by the experienced judgments we received.

Many of these inputs have already been woven into the analyses of the preceding chapters, and also in Chapters III and IV. There are some themes present in the perceptions of those interviewed, however, that should be emphasized by presenting them here as general lines of thought, without thinking of them only in the context of a particular industry or program.

One somewhat unexpected observation was the general agreement between government and industry executives on major approaches to government-industry interactions. The simple concept that effective government involvement in civilian-sector R&D called for private-sector linkages in planning, in conducting R&D, and in converting results to use emerged from both sectors. The need for guidance based on market considerations was axiomatic to all with regard to technology that could lead to products and processes integrated into the civilian economy.

There was equal comparability in discussions as to what factors could justify government activity in civilian-sector R&D -- questions of important public interest, disaggregated industry structure, general needs for supporting the technical infrastructure. This should not imply complete agreement, but remarkably similar listings emerged from government and industry representatives.

Clearly, our discussions were with operating executives of both sides, not ideologues. These were thoughtful people who had spent their professional careers in addressing the question of generating and using technical change. The similarity seemed to override the adversary tendency one often expects to encounter in government-industry dialogues on economic or social questions.

Thus, industry representatives provided examples for constructive government activities, not arguments for a complete withdrawal from government intervention. Their views mirrored to a large extent the conclusions of the economic histories described in II C (above). There was a general consensus on these broad points:

* The government should fund basic scientific research and support generic technologies.

* The government should stay out of applied research whenever it is not itself the final customer for the products involved.

* Cooperative research among companies -- or among companies and government -- is possible in a rivalrous industry only on matters "peripheral" to the industry's main concerns.

* The government should support scientific and technical infrastructure -- facilities, teaching, and especially manpower training.

In a similar manner, government representatives suggested a need for the sorts of interactions that have long been advocated by industry. Among these are:

* Involvement of industry perssonel to help set priorities and to inform planning based upon market developments and general business plans.

* Cooperation with active industry R&D programs in relevant areas.

* Desirability of exclusive licensing for optimum exploitation of government-supported R&D when appropriate.

* Exposure to industry needs in underlying scientific and eingineering fields.

An important substantive issue surrounds the fact that, historically, government R&D activity evolved from strictly public-sector areas. This set certain precedents for contract instruments, accountability of funds, and distinctions between grants and contracts. The general -- and perhaps unfortunate -- thrust has been to treat federal funding of even civilian-sector R&D as "procurement" rather than as assistance.[26]

It is not critical to review the details of these issues here. Major reviews have been carried out by OTA and OMB, among others.[27] The important point to note is that the issues are being approached by government agencies with the intent of improving the conduct and transfer of R&D, and to stimulate interactions with the private sector.

Thus, a first optimistic conclusion from these inputs is that, at a very broad level, responsible personnel in the public and private sectors have a similar appreciation of the factors entering into the process of technical change in industry. This is not a trivial asset in creating a future system for the effective use of our total technical resources.

The allocation of federal R&D resources intended to benefit the civilian sector appears to require at least two conditions: support within industry and understanding within government. Both rely upon a corps of senior executives who approach the issues in a professional and rational manner. The existence of these individuals in government and industry is an important basis for improved effectiveness in future activities.

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26. This view is also expressed in a report by the Office of Technology Assessment, Applications of R&D, Washington, D.C., June, 1978.

27. The Federal Grant and Cooperative Agreement Act of 1977 mandated a comprehensive two-year program of federal assistance to be conducted by the Office of Management and Budget, Office of Federal Procurement Policy. For part of this review see OMB, Toward a Uniform Procurement System, Washington, D.C., July, 1980.

III. GOVERNMENT POLICY AND TECHNICAL CHANGE: LESSONS FROM HISTORY.

A. Analyzing a Complete Historical Record.

This chapter is an attempt to summarize and interpret the results of this study's principal analytic project: historical case studies of technical change in seven major industrial sectors.[1] The studies themselves, along with a more detailed analysis, are available separately as the second volume of this report.[2] The studies describe -- in some cases in considerable detail -- what the most important government policies have been, the reasons for those policies, and (albeit often in qualitative terms) how those policies have influenced technological change.

Most analytic attempts at understanding the implications of government involvement in technical change -- including those prefatory to launching new government programs to stimulate such technical change in industry -- have tried to begin *de novo*. Sometimes they have attached themselves to one or another economic theory relating R&D to economic growth; often they have looked about for industries potentially in

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1. The case studies and their authors are: agriculture (Robert Evenson); automobiles (Lawrence J. White); commercial aviation (David Mowery and Nathan Rosenberg); computers (Barbara Katz and Almarin Phillips); housing (John Quigley); pharmaceuticals (Henry Grabowski and John Vernon); and semiconductors (Richard Levin).

2. Richard R. Nelson, ed., *Technical Change in U.S. Industry: A Cross-Industry Analysis*, New York: Center for Science and Technology Policy, 1981. (Forthcoming in 1982 from Pergamon Press.)

need of a stimulus to innovation. But few studies have recognized that government involvement in industrial innovation is a process with a long history, one rich in clues for those who seek the path of successful government policy.

The imperatives of theory and history are always at odds. Theory simplifies; history complicates. But a theory disciplined by history is likely to be a robust one, one attentive to idiosyncrasy and detail. The U.S. policy experience in industrial innovation -- as captured in our seven industrial studies -- reveals a good deal of complex detail demanding our attention.

1. A Brief Review.

From the beginnings of the industry, the federal government has been a major stimulator and support of technological advance in aircraft. Military procurement has, at virtually all times, accounted for a significant fraction of total sales of the industry. Direct government support of R&D has taken several forms. During the heyday of NACA, government funds supported R&D and testing relating to aircraft in general; during this time the generic aspects of military and commercial technologies were relatively undifferentiated, and advances in understanding or design principles relevant to one usually were relevant to the other as well. Of course, the government funded R&D on airframes and components intended for specific military needs, although in many cases the companies invested their own funds in hopes of winning a procurement contract. Since World War II, government R&D monies have gone largely into work with specific military applications in mind. It has turned out that a good portion of military technology continues also to be applicable to civilian aviation, although recently these technologies have been drawing apart.

The post-war era was also marked by a government attempt to instigate and support the development of a commercial supersonic transport -- an experience that ended as an expensive abort. CAB regulation of the airlines, and the constraints on vertical integration imposed by the Airmail Act of 1934, also have been important influences on the way civil aircraft technology has evolved.

There has also been a strong military, and space, interest in computer and semi-conductor technology. In semi-conductors, most of the early work that laid the foundations for the industry was privately financed. Government R&D funding came later. By contrast, much of the early exploratory research on computers was done under government contracts. Government procurement accounted for a large percentage of the sales of both industries in the early days. While, as the industries began to tap commercial markets, government procurement and R&D funding came to play smaller roles, the government market continues to be significant in both industries. Public monies have continued to support advanced education and university-based research relevant to these industries. Anti-trust considerations have played an important role in the evolution of both industries. Had Bell Laboratories and Western Electric gone into commercial production of semi-conductors, the industry likely would have taken on a shape very different than it did. Anti-trust controversy seems to swirl continuously around IBM because of the dominant position it has achieved in the commercial computer market.

For many years, public funds have supported applied and basic research, higher education, and extension services for agriculture. Unlike the stiuation in the three industries mentioned above, in the case of agriculture there has been no major public procurement interest. However, the farmers of the United States have formed a strong political constituency demanding, and to some extent guiding, government R&D support. The public R&D system has been operated largely through the agricultural colleges and experimentation stations of the state universities. Decision-making in R&D allocation has been largely decentralized to the individual stations, which depend on their state legislatures for a hefty portion of their funding.

In pharmaceuticals, as in agriculture, significant federal monies have gone into basic research, and into the establishment and maintenance of programs to train scientists. However, federal funds for pharmaceutical applied research and development have been fenced into the are of "orphan drugs" for which the commercial market is likely to be small. It is apparent that there exists a strong political constituency for basic research funding; at the same time, there are strong political constraints against significant federal encroachment into the proprietary domains staked out by the pharmaceutical companies. Pharmaceuticals is also an industry marked by a complicated regulatory regime that affects the cost of R&D significantly.

The automobile and residential construction industries have experienced neither significant federal procurement nor much federal R&D support for either basic or applied work. Regulatory regimes, however, have strongly influenced technological advance in both sectors. Both sectors have seen federal attempts to launch an R&D support program. But political support for these has been weak; and where programs were initiated they were not sustained.

2. The Analytic Problem.

How can lessons be drawn from the rich experience described in the case studies and from other studies? In principle, we want to draw up a matrix. The rows would delineate various policy instruments; the columns would enumerate various industry characteristics; and the entries would measure the feasibility and effectiveness of a policy under a particular set of industry characteristics.

The task, so defined, remains impossible. Simply classifying the policies and the relevant industry characteristics is a challenging task; tracing cause-and-effect relationships is extraordinarily difficult.

In general, a wide variety of policies have impinged on each economic sector and each policy has been complex and changing over time. In both aviation and agriculture, government funds have gone into support of applied R&D; but the programs and the objectives are very different in these two cases. Regulation has meant different things in automobiles and in pharmaceuticals. And there is no obvious "list" of policy instruments one can think of to define the rows of the matrix. Indeed, simply describing and broadly characterizing the various government policies employed is itself a complicated and worthwhile research endeavor.

What are the industry characteristics that determine the feasibility and likely effectiveness of various policy instruments (assuming these can be well described)? Why has major government R&D support proved feasible and effective in aviation, but not in residential construction? The question suggests that one important industry characteristic is the presence or absence of a well-defined procurement interest. Perhaps so; but government R&D support has been feasible and effective in agriculture. What differentiates agriculture from housing? Simply identifying the key industry characteristics that seem to explain these differences is a challenging analytical task.

Even if we could lay out the rows and columns in an objective manner, cause-and-effect relationships are not easy to discern; technological progress in an industry might be fast or slow and take the particular directions that it did for any of a wide variety of reasons. Given the current state of knowledge, it is not possible to estimate a policy's effect with any precision. To what extent did public R&D money simply replace private R&D monies in the early days of the computer industry? In aviation? Has public R&D support really made a difference lately in semi-conductors? To what extent has regulation deterred pharmaceutical innovation? These are very difficult questions.

In short, it is very hard to tease out from the historical record clear-cut lessons that are applicable to future policy decisions. But let's try anyway.

Much of what follows will obviously be judgmental. We will be presenting, in effect, a set of hypotheses about the kinds of policies that are feasible and effective in various contexts. While we believe they are consistent with the historical record as revealed in the case studies -- and with other evidence -- this theory, like any theory that fits a fragment of evidence, may prove quite wrong in a number of places or even in a broad scope.

We are interested ultimately in understanding the sources of variation. Different policies have been applied in different industries. Some have been smashing successes; others have been ineffective or worse. However, in order to sort out the characteristics, reasons for, and effects of variation, it is important to get hold of the common elements. There are several general characteristics of technological advance that are apparent in all the case studies. One is the apparent inherent uncertainty involved in technological advance. A second is the central, but often myopic and strongly context-dependent, role of producers and consumers in the generation and screening of technological advance. The third is the important role played by non-market elements (as well as market ones) in the institutional structure influencing technological advance.

All of the case studies reveal that technological advance involves considerable uncertainty. When a person or organization begins the quest for a new product or a process, it is never clear exactly what the precise outcome will be. Design configurations and solutions take shape only gradually; and the ultimate success -- or failure -- of the quest is revealed only after the fact. The uncertainties take on a somewhat different form in each technology. Thus Grabowski and Vernon describe the hunt for a new pharmaceutical as, literally, a search. Katz and Phillips discuss the considerable uncertainty during the 1950s regarding which new technology was going to replace the old vacuum tube in computer design. Mowery and Rosenberg point out that, in the design of civil aircraft, theoretical calculations resolve only a small portion of the uncertainties. Some of the semiconductor companies placed their bets heavily on integrated circuits; others hung back.

Technological uncertainties are compounded by market uncertainties -- which future technologies will be useful, and which will be bought at a profitable volume and price? Just as different individuals and R&D organizations lay their bets differently about which technological paths are the most promising, so they tend to differ in their assessment of the market. A number of companies that developed strong technological capabilities for the design of computers failed to anticipate a large business market. IBM made a bet that such a market existed at the same time that it acquired the technological capabilities to cover the bet. The American automobile companies had little reason to believe that consumer demand would swing sharply towards smaller more fuel efficient vehicles, but it did.

Thus, while the details differ from industry to industry, in none of the cases do R&D and follow-on technological work appear to be activities that are "plannable" in any neat and tidy sense. The uncertainties seem to be innate. From a social point of view, effective pursuit of technological advance seems to call for the exploration of a wide variety of alternatives and the selective screening of these after their characteristics have been better revealed -- a process that seems wasteful with the wonderful vision of hindsight. As the supersonic transport case indicates, however, hindsight may be much clearer than foresight.

All of the case studies also reveal the central role of the producer-provider (usually private enterprise) or the demander-user (who may be private or public) in the generating and screening of technological advances. The producer, and the user, each have certain informational and motivational advantages over other parties. Producers live with the prevailing process and product technology, and know things about it -- its strengths, its weaknesses, certain potentialities for change -- that people and organizations without that experience cannot know. Users have similar special knowledge about the products and services they employ. It is natural, and essential, that this special knowledge and immediate motivation for improvement play a central role in inducing and guiding the innovation process. Moreover, in a market setting it is users who ultimately will determine whether a product will be demanded, and producers whether it will be produced and how.

This said, it should be recognized that the vision may be narrow, and that motivation is very context-dependent. Both the computer and semi-conductor case studies reveal companies reluctant to move away from technologies with which they were familiar to try radically different ones. In the semi-conductor case, it is interesting that new companies, not the old tube producers, were the key innovators. Similarly, user-consumers, like producers, fall into comfortable habits. Had IBM waited for potential users of business computers to articulate a clear-cut demand for them before deciding that a market likely existed, the advent of the computer age would have been significantly delayed.

The motivation of the producer and user is strongly influenced by the details of the technologies involved, and by the particular institutional and legal setting. There is little gain for a for-profit seed vendor to develop better self-propagating seeds. (It does pay the seed vendor to develop better hybrid seeds since the farmer has to go back to the source each year; he cannot create next year's seeds from this year's plants.) It was a delicate, and not inevitable, legal decision that ruled that antibiotics, although natural substances, were patentable. While patents don't carry much force in the semi-conductor industry, and innovations are quickly imitated, the advantages of a head-start are still significant enough that firms have motive to innovate. Government regulation, much more than expressed consumer demand, has pulled innovation towards safer and less environmentally harmful automobile designs. CAB regulation, in the form of constraints on air fares, tilted airline competition toward providing more attractive service, and stimulated the market for faster and more comfortable planes. It was a governmental market, not a private market, that made it profitable for Texas Instruments and IBM to invest in semi-conductor and computer R&D. Both building codes and fluctuations in the demand for housing significantly dampen incentives for innovation in building construction.

In sum, while producers and consumers play central roles in the innovation process -- and they should -- their informational advantages may also be associated with myopia. Their motivations are strongly influenced by special technological circumstances and the particular legal and institutional setting and by public as well as private demands.

More generally, it is important to recognize that technological change involves non-market as well as market elements. In all of the industry studies presented in the accompanying volume, there was a "public interest," expressed through public policies, in certain aspects of the performance of the industries. There were elements of cooperation as well as competition in research and development.

In aviation, computers, and in semi-conductors, there was, for obvious reasons, a public interest in how the technologies and the industries evolved that transcended the interest of particular private purchasers or producers of the products. In these cases, the public interest was manifested in a governmental demand for goods and services of a quite specialized variety and in policies associated with procurement.

In the other four industries studied, there was no such important procurement interest. However, a public interest in certain aspects of industry performance shows up in other policies. In the case of pharmaceuticals, automobiles, housing, and agriculture (as well as aircraft) a public interest in safety, environmental protection, and in ensuring certain general standards was made manifest in regulations. Several of these industries also are marked by various forms of subsidy to producers or consumers. Citizens and scholars may divide on the merits and demerits of these regulations and subsidies. But this makes it no less a fact that public policies to constrain or supplement market mechanisms pervade the American economy. And the workings of these policies significantly influence the environment for industrial innovation.

Further, the R&D systems of most industries involve both competitive and cooperative elements, the latter often university-based. In all of the industries surveyed, for-profit firms creating and taking a proprietary interest in certain technologies are a large part of the story. But in all of the industries one can also observe a system of R&D cooperation and the exchange of technological information. In some cases, government policy has played a large role in building and supporting this cooperative system; in other caes, a smaller role.

With these common elements laid out, we can now explore the differences in policie', in industry characteristics, and in the apparent viability and effectiveness of policies, revealed by our case studies. (In what follows, we also draw, where appropriate, on other studies.) As stated at the outset, one cannot directly lay out a matrix. But there are several alternative paths to follow. We could try to assess what industries are success stories in some sense and discuss the policies and structures associated with these -- and then go on to discuss the failures. We could also divide the industries according to some kind of structural characteristics. It has proved more straightforward to try to classify policies (instruments) and proceed to consider where they were and were not employed and why, and how effective they have been in various contexts.

3. A Road Map.

One rough division among instruments places those that involve direct government funding of R&D in one category and those that indirectly influence R&D or other activities involved in industrial innovation in another. While this division is plausible on its face, notice that the lines between the categories are blurred, not sharp. How does one treat, for example, procurement contracts that cover the cost of R&D incurred earlier by a company who anticipated the subsequent contract? How does one treat special tax credits for R&D? These problems notwithstanding, we shall hazard such a break.

The objective here will be to categorize meaningfully the various kinds of government R&D support programs revealed in our case studies -- to analyze the reasons for the significant differences in such policies across industries and to make judgments as to which kinds of programs worked and which didn't. We should distinguish among four kinds of government R&D support programs: (1) those associated with public procurement or other well-defined public objectives; (2) those that involve an extension of support of scientific basic research to support of research to advance generic technological knowledge; (3) programs that are aimed at meeting reasonably well-defined clientele demands; and (4) the policy of picking or supporting "winners" in commercial competition.

In Section C below, we will consider a wide range of government policies that do not involve direct R&D support -- procurement regulation both old style and new, anti-trust policy regarding patents -- to name only the central ones. But simply listing these as instruments covers up some fundamental problems. Regulation, for example, has meant fundamentally different things in different industries; the thrust of antitrust policies also have been different; etc. Relatedly and equally importantly, the central purpose of these policies often has little to do with spurring or guiding industrial innovation. There are serious questions as to whether they should be regarded as promising instruments for that purpose.

B. <u>Government Support of Research and Development</u>.

The case studies reveal significant differences among the industries in the extent and kind of federal R&D support. The government has been an important source of both applied and basic research funding in the evolution of aviation, computer, and semi-conductor technologies. The government has also productively supported both applied and basic research in agriculture. While the government has been an important supporter of basic research relevant to pharmaceuticals, public funding of applied research and development has been mostly constrained to "orphan drugs." The government never has been able to mount a sustained R&D program relevant to the housing and automobile industries.

It is not easy to measure the efficacy of the various government R&D support programs. In the three defense-related industries, they certainly have bought us technological primacy. Critics have argued both that much of the bought-technology has not been necessary for national security but rather has inflamed the arms race, and that many of the R&D programs have been inordinately expensive and wasteful. It should be noted that contributions to the advance of civilian technology made by defense and space programs, while not the focus of our case studies, has been a "spill over" and certainly not the principal intent of these programs. The advance of civilian technology was the central purpose of the government R&D support programs in agriculture, and of basic bio-medical research. The rate of return on the public investment in R&D for agriculture undoubtedly has been very high. Quantitative estimates are more difficult with respect to the returns from support of bio-medical research; however, this too is generally regarded as a very successful research program. The case studies also reveal two expensive fiascos -- the supersonic transport project and "Operation Breakthrough" in the housing industry.

How can one make intellectual order out of this varied experience? It is important to distinguish among the following categories of government R&D support programs. First, R&D support aimed to achieve a well-defined government purpose -- such as the procurement of a new weapon system or the solution to the automobile emissions problem. Second, support of basic or generic research relevant to a particular technology or technologies and not pointed toward achieving any particular product or process -- such as research on the nutritional needs of wheat or the properties of certain exotic materials. Third, support of applied research and development on products and processes that serve civilian, not governmental, purposes and whose acceptance depends in large part on market calculations made by non-governmental actors. This last category ought to be further divided, perhaps, into programs in which the potential users have a considerable influence on allocation and program in which a government agency has relatively free-handed control over the setting of goals and priorities. Programs obviously differ in the range of industries for which they are politically feasible and in the kinds of circumstances in which they are likely to be effective.

1. R&D Support Associated with Procurement Needs or Other Well-Defined Purposes.

In three of our case studies -- aviation, computers, and semi-conductors -- there was a strong and recognized governmental demand for the products produced by the industry, which led to a particular and focused public interest in certain kinds of technological advances. A recognized public sector demand for certain types of technological improvement lends two important features to the policy context. First, it means that the government (or the relevant government agent) is in a position to define technological targets according to its own criteria and that it has (or at least has the motivation to have) some expertise about the technologies in question. Second, the recognized governmental need lends legitimacy to government attempts to stimulate and guide the evolution of the relevant technologies.

One should note that public procurement does not inevitably lead to active public-sector effort to mold or stimulate type technological advance. The federal government procures typewriters, office calculators, automobiles, and a wide variety of products that are identical (or virtually so) with those purchased by non-governmental users. In these cases, the federal government usually has chosen simply to act as an informed shopper. Even in cases in which government demands are somewhat special, the government has not always stepped in with a special procurement contract for the creation of a product tailored to its use or even strongly advertised its special interest through an implicit promise of procurement. In the three industries in question, however, the relevant government agencies deliberately tried to induce the development of products that were suited for their purposes. The vehicles employed included procurement contracts written so as to cover the R&D costs of the particular design (a disguised form of R&D support), direct R&D support associated with a procurement contract, and support of basic and generic research.

If public-sector needs and private-sector needs differ sharply, the procurement and applied research and development funding aspects of such policies would not facilitate the evolution of technology for the private sector. At least three cases suggest, however, that government efforts to advance technology for public sector purposes can also enhance technological capabilities to meet private needs. In the early days of these technologies, R&D aimed at a governmental purpose almost always had some commercial spill-over. As these technologies matured, the governmental (military) market and the civilian market began to separate, with the civilian market becoming increasingly important to certain companies. Government-financed applied research and development associated with public procurement became increasingly distinct in form from R&D financed by the companies themselves and aimed at products in the civilian market.

At the present time, the principal impact of the government on the evolution of a civilian technology in these industries would appear to come via public support of basic and generic research. This fall-off in "spill-over" has led to proposals that the government consciously fund projects that have likely civilian benefits. The supersonic transport ought to warn against this strategy; and we shall present some general arguments against it later in this section.

The lesson to draw from these cases is not basically one about the efficacy of "spill-over." The lesson is that the government has the capability intelligently to fund applied research and development as well as basic and generic research when there is a well-defined public interest in particular kinds of technological advances.

Orphan drugs are another case in point. Here, as with the examples of defense procurement, a government agency stands ready to see that the fruits of R&D are employed. There is a recognized public commitment to try to cure or relieve the suffering of people with grave diseases. If necessary, public monies will go into the procurement of whatever it takes to do this. Thus, orphan drugs are not, as it were, in the position of having to make it in a conventional commercial market. As with the case of the decision by the Department of Defense to procure a new fighter (or as with the space program) one can argue about how much tax money ought to go into the pursuit of the objective, and about whether the program is being conducted efficiently. But there is little question about the political legitimacy of the program, or about the potential ability of government decision-makers to marshal the information needed to make sensible R&D decisions.

The case of pollution abatement is similar in context, if not in policy. Since the middle 1960s, there has been a well-recognized public interest attached to the development of technologies that are less polluting than those currently being employed. Some public monies have gone into R&D on pollution abatement. But the Clean Air Act of 1970 marked a commitment to a strategy for achieving the objective that minimized the government's direct role in funding R&D. Rather, the strategy was to induce private funding of R&D through the imposition of regulatory requirements that could be met only by the development of new technologies. White and other scholars have argued that this has proved an inefficient and costly way of drawing forth the new technologies. Given a recognized public commitment to their achievement, the government certainly was in a position to fund R&D on its own and to organize to gain the information needed to make sensible R&D allocation decisions.

The examples that come from our case studies suggest two things. First, there is a wide range of technologies associated with public procurement (or public subsidy of certain kinds of private purchases or regulation) for which particular technological advances are recognized public objectives. Second, the government has adopted a wide variety of strategies on the extent and kind of R&D it will support in these areas. At one extreme, the government has financed the bulk of the relevant R&D; and at the other it has stood passively as a consumer. While assessment of this assertion depends on a case-by-case evaluation, one could argue that, in many cases, the government has been too passive, that the returns to public funding of R&D on public needs would be very high, and that indirect means to "pull" technology (as through regulation) often are more costly and less efficient than direct R&D support. Note that the argument here is not that the government support of such R&D would have significant "spill-over" benefits. It is simply that there are a large number of technologies for which there is an identifiable public interest in certain kinds of advances, and in many of these cases federal R&D funds could be spent to yield a high social rate of return.

The efficacy of such programs depends, however, on the ability of the relevant government agencies to gether the appropriate information and make sensible R&D allocation decisions. Access to such information implies strong participation by users. R&D support programs have to be designed to achieve this participation. The development of better technologies for the provision of public services -- e.g., for mass transport, garbage collection, repairing city streets, etc. -- can potentially yield a very high rate of return on the public R&D dollar. However, when -- unlike the Department of Defense -- the Department of Transportation or the Department of Housing and Urban Development make R&D allocation decisions, they are not usually making them regarding items that they themselves will procure. The principal users will be state and local governments. Similarly, public financing of the R&D required by the environmental and safety goals may yield high social returns and avoid the high private costs and tangled relations that come from the current regulatory strategies. However, the new technologies will ultimately be employed by private firms, not federal agencies. The institutional machinery needed to spend such public R&D monies efficiently will have to be different from that of the Department of Defense or NASA. Perhaps the pluralistic decentralized structure of the government's agricultural R&D support programs would provide a better model.

2. <u>Support of Basic and Generic Research</u>.

Absent a recognized public interest in the evolution of a particular technology, certain constraints appear on the government's ability to fund R&D. In the first place, a government agency has no particular claim to be able to determine R&D priorities, and may be blocked from access to the information necessary to do so. Second, the legitimacy of publicly financed R&D programs, which may upset the *status quo* within an industry, may be questioned and such programs blocked politically. These constraints are particularly binding with respect to applied R&D aiming to achieve particular new products and processes. They appear to be much less confining for public support of basic and generic research a step or two away from specific application.

Our case studies show the government actively involved in support of such research not only in the three industries in which there was a strong procurement interest -- aviation, computers, and semi-conductors -- but also in agriculture and the scientific fields relating to pharmaceutical developments.

The aborted Cooperative Automotive Research Program represented an attempt to extend this type of public program to the automobile industry.

To understand the nature and importance of these public programs, it is important to recognize that technological knowledge inevitably involves a public as well as a proprietary component. The public part of technological knowledge generally does not relate to the design or operational details of a particular product or process but to broad design concepts, general working characteristics of processes, properties of materials that are used, testing techniques, etc. Most of such knowledge is not patentable. Much of it is openly shared among scientists and engineers working in the field, whether they are located at universities, government laboratories, or corporate laboratories.

The kind of research that leads to such knowledge is not generally the sort that an academic scholar, pursuing fashionable questions in a standard scientific field, would explore. Rather, the research questions are posed by technological problems and opportunities, and the objective is to enhance that understanding and the capability to solve practical problems. In some industries, progressive private companies themselves support some of this type of research. While some secrecy is involved, it is recognized that the findings from this type of research ought to flow into the public domain. Such a research system fits in between more fundamental research defined by traditional sciences, and the applied research and development of the firms in the industry. To be effective, the system has to make good contact with both sides but avoid too much overlap and duplication.

In the judgment of Evenson and other scholars the agricultural sciences have in general managed to define their niche appropriately. The research they do lies in between the basic academic sciences like chemistry and biology on one side, and the research that goes on in public experimentation stations and private companies on the other side, to develop better seeds or fertilizers, etc. Both sides influence the kind of research that is done and monitor quality and efficacy. The bio-medical research community is a similar system. It too is pulled from one side by the interests of practitioners (physicians) and private companies in having practical problems illuminated, and is disciplined from the other side by scientists in the more basic sciences. It is interesting that both the agricultural sciences and the bio-medical sciences tend to find their home in universities -- but in professional schools rather than in colleges of arts and sciences.

The government provides the bulk of support for these two research communities. The allocation of research resources, however, is guided only loosely by government agencies. The Department of Agriculture, the state legislatures, and the National Institutes of Health -- the principal support agencies -- leave the details of allocation to machinery operated by the research communities themselves. However, in political deliberations about the level of funding and broad research strategies, the focus is very much on the practical benefits that have flowed from the programs and the practical problems that future research promises to resolve.

Mowery and Rosenberg remark that the old NACA did not sponsor much in the way of basic research. In the pulling and tugging to be applied and relevant on the one hand, and to be rigorous and scientific on the other, the first kind of pull clearly was significantly stronger than the second during the '20s and '30s. This well may reflect the fact that NACA, unlike the agricultural experimentation stations and the medical schools, was a free-standing organizational entity not affiliated with a university or universities. Nonetheless, NACA undertook many experiments and studies that were relevant to aviation technology in general, rather than concentrating on particular aircraft designs that were being contemplated or were on the drawing board. In that sense, NACA certainly did support generic research and, as history testifies, to strong positive effect. The role of NACA diminished after World War II. In the post-war era, the armed services increasingly funded their principal contractors to do the kind of research that NACA used to do.

No sharply separate generic research programs mark the computer and semi-conductor industries. While sometimes special government agencies were involved (for example, the Advanced Research Projects Agency of DOD), government funds for generic research for these technologies -- as in aviation after World War II -- have flowed to companies and to the universities. But this research support has been very important. Funds continue to be significant.

The aborted experience in CARP suggest that government programs in support of basic and generic research can be acceptable in virtually any industry, though the specific conditions must be discussed with all concerned. Companies do not perceive such programs as posing sharp threats to their commercial positions, or the thr[illegible]s [illegible] perceived are seen as diffuse and not readily ident[illegible]es dangerous to any particular portion of the industry. Such proprietary knowledge is not needed to guid[illegible]cation; mechanisms can be established to allocate resources sensibly. However, this must be done without disruption to planned private research if it is to be supportive.

The key question is the efficacy of such programs. In the industry studies we have conducted, the verdict is positive. Where private companies support little generic research, the case for public support seems specially strong. Where private companies support such research, the case for public funding is diminished, but certainly not eliminated. Thus in the computer industry and in semi-conductors, where the companies themselves do engage in significant funding of generic research, there is advocacy of, not opposition to, government funding of research at universities. (There is, of course, a risk that public funds in such cases largely replace private funds rather than adding to them.)

Perhaps, then, programs like the Cooperative Automotive Research Program (CARP) and the Cooperative Generic Technology Program (COGENT) proposed during the Carter administration,[3] are not entirely misguided in concept. "Generic" research programs might well be an appropriate topic of discussion during the next resurgence of concern within policy circles for boosting industrial innovation.

3. Support of Clientele-Oriented Applied Research.

Public support of basic and generic research does not require program officers to form judgments about which particular technological developments would be most valuable. Rather, the objective is to enhance understanding of relatively basic principles or to explore certain potentially widely applicable technological routes. Furthermore, this kind of research seldom poses an immediate perceived threat

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3. Cf. Chapter IV below.

to the proprietary interests of particular groups or firms. In contrast, government programs of support of applied research and development for an industry whose products are evaluated largely on commercial markets requires a mechanism for making commercial judgments and may provide some significant perceived threats to particular firms.

The case of public support of applied research and development for agriculture indicates that, even with these constraints, a feasible government program may be effective. It is interesting to consider which aspects of the industry, and the program, have permitted an effective program.

In the first place, farming is an atomistic industry, and farmers are not in rivalrous competition with each other. Differential access to certain kinds of technological knowledge, or property rights in certain technologies, are not important to individual farmers. This fact at once means that farmers have little incentive to engage in R&D on their own behalf and opens the possibility that the farming community itself would provide a political constituency for public support of R&D.

The federal/state agricultural experimentation system, established under the Hatch and subsequent acts, marshalled that support and put the farmers in a position of evaluating and influencing the publicly funded applied R&D. The system is highly decentralized. The regional nature of agricultural technology means that farmers in individual states see it to their advantage that their particular technologies be advanced as rapidly as possible. Where private companies are funding significant amounts of innovative work and the industry is reasonably competitive, it is in the interest of the farmers, as well as the companies, that public R&D money be allocated to other things. As Evenson describes it, a reasonably well-defined division of labor has emerged between publicly funded and privately funded applied research.

Evenson and other historians of technical change in agriculture have argued that the applied research and development efforts of the experimentation stations did not yield particularly high rates of return until a body of more scientific and technological understanding was developed. It was this combination of an evolving set of agricultural sciences based in the universities and supported publicly, and applied research and development also publicly funded but monitored politically by the farming community, that has made public support of agricultural technology as successful as it has been.

Can the experience in agriculture be duplicated elsewhere? It is apparent that many people have seen housing and agriculture as quite similar. Henry Wallace, who earlier served as Roosevelt's Secretary of Agriculture, clearly drew the analogy when, after the war, he tried (and failed) as Secretary of Commerce to initiate a major program of federal funding of building research. The efforts to revive that idea under the Kennedy administration also were explicitly based on the agricultural analogy. The analogy was also drawn in "Operation Breakthrough." It is obvious that there are important differences.

In the first place, while the building industry is atomistic, construction markets are local and therefore builders are, to some extent, in rivalrous competition with one another. However, since individual builders possess little in the way of proprietary knowledge, this was not a particularly important obstacle. What was more important was that suppliers of inputs and equipment to builders produce different, and rivalrous, products. Direct government support of applied research and development was viewed by many of them as potentially threatening. Had the builders of houses formed a strong constituency for government support of R&D, these resistances of input suppliers might have been overcome. However, no such constituency developed. Unlike the case in agriculture where farmers saw it to their competitive advantage (as a group) to have their technologies advanced relative to the technologies employed by farmers in other regions, builders apparently saw no such advantages for them.

Nor did there exist in housing, as there came to exist in agriculture, a scientific community that could point persuasively to promising areas for applied research and development. Residential construction lacks a broad scientific base from which to mount applied research and development endeavor.

Thus agriculture had both a constituency interested in getting applied research and development relevant to their needs undertaken and, ultimately at least, a sound scientific basis beneath its technologies. Residential construction has neither. One may conjecture that programs in support of residential construction technology will not be politically feasible until the clientele is established to support and guard them, and will not be effective in the absence of some sort of underlying scientific base.

It probably is the case, therefore, that the agricultural model of public support of applied R&D is not readily extendible to many other industries. There may be a few, however, to which such a program is applicable. Again, the key ingredients would appear to be (1) a group of users of a technology who are not in rivalrous competition with each other but who, together, have a significant interest in getting their technologies advanced and (2) a scientific base strong enough that applied research and development can be fruitful. One might also note that these are the conditions under which one might think of establishing industry "cooperative" research and development laboratories. Indeed, the agricultural experimentation stations might be regarded as just that -- except for one important difference. Much of the policy discussions about cooperative research and development has presumed that public funds should account for only a small portion of total R&D monies, and that the industry should contribute the bulk of the funds save for, perhaps, the first few years of the program. Under such terms, it has proved hard to get much cooperative R&D underway and sustained. The agricultural case suggests that the requirement for industry financing may be a mistake. In industries -- like agriculture -- where such programs are plausible, prices tend to follow costs. The returns to successful R&D go largely to consumers, not to producers. The difficulty with extending the agricultural model is not that the public at large would not benefit, but that the conditions under which this model is applicable would appear to be rather special.

4. Government-Guided Applied R&D with Commercial Ends.

In Operation Breakthrough and the Supersonic Transport Project, the government got itself into the business of trying to identify or develop products that would sell well on complex commercial markets. In Operation Breakthrough, the Department of Housing and Urban Development was neither itself a major builder of houses nor a buyer of non-subsidized housing. It thus did not have any particular expertise for judging what types of designs would be most promising, let alone which would likely sell or rent. Thus it was easy for the Department -- and Congress -- to lose track of the objectives as the program was debated politically. Similarly, the

FAA was not in the business of building, or procuring, commercial airlines. The commercial airlines were singularly discouraging when asked about their interest in a supersonic transport. The aircraft producers showed no particular interest in designing and building such a vehicle until the subsidies grew very large.

Very few of the housing designs created through Operation Breakthrough proved viable commercially, nor did they serve as a significant basis for follow-up design work. The British/French experience with their supersonic transport indicates how fortunate the United States was that the program was stopped before it resulted in a technologically (though not commercially) viable aircraft.

The lesson here is not particular to these two cases; it is a general one. There are many other studied cases, most of these European, in which the government has tried to identify and support particular products they hoped would ultimately prove to be commercial successes. While there were a few successes, the batting average has been very low except where the government in question has been willing to subsidize, or require the procurement of, the completed product as well as the R&D on it.[4]

This should not be surprising. In many of the industries in which this has been attempted (in Europe), the private companies also were investing in R&D, and the government was in a position either of duplicating private effort; subsidizing that effort and probably therefore

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4. See, generally, K. Pavitt and W. Walker, "Government Policies Toward Industrial Innovation: A Review," Research Policy, Vol. 5, No. 1, January, 1976.

replacing private R&D monies; or investing in a design that the private companies had decided to leave alone. In the last case, it might be argued, there is a legitimate public role in supporting work on designs that are a generation ahead of those that the companies themselves are exploring. However, as the supersonic transport and a number of other like examples indicates, the sensible way to explore the next generation of technologies is through doing generic research, building and studying prototypes, etc. The appropriate research program is one modeled after NACA, not one modeled after the supersonic transport project.

If the United States were to drop its anti-trust laws, and the objective of preserving intra-U.S. competition that those laws are supposed to embody, then it might be possible to mount a policy to help industry search for "winners." In various of the European countries -- and Japan -- competition is viewed not so much in terms of rivalry among domestic companies but in terms of competition from abroad. In these circumstances, it is possible for a government to work with industry as a whole, and to participate in laying the bets, and in dividing of the market. As the law exists in the United States, much of the information needed to guide a government program to help industry find and support "winners" is proprietary, not shared among firms, and not accessible to a governmental body. The experience of the European governments in trying to pick winners indicates the costs of these American constraints are not severe; constraints are looser in Europe and the record of public policies to help industry identify and support winners is not encouraging. The experience in Japan may or may not be different. As the present time not enough is known about what the Japanese actually do to make a judgment on this. In any case, modes of government-industry cooperation in Japan are so radically different from those in the United States that it is doubtful we can learn much of use to us from the Japanese experience.

It is a shame that so much of the discussion about government support of industrial R&D in the United States has swirled around the question: should the government try to pick winners? The evidence from our case studies answers that question with a resounding no. However, the experience also shows that there are many other potentially fruitful ways that the government can support industrial research and development.

C. Policy Affecting the Climate for Private R&D.

Much of the preceding section was spent disentangling various kinds of government R&D support, attempting to identify the reasons why such support has taken different form in different industries, and hazarding guesses as to the effects. The same kinds of analytical challenges face us in this section, which is concerned with a variety of government policies that have influenced the climate for private R&D and innovation but which do not involve direct governmental support of R&D. Regulation, for example, has meant very different things in the various industries studied.

The fact that the policies considered here do not involve direct R&D support may not be the most important difference between these policies and those considered in the preceding section. The policies discussed above were obviously intended to influence technological advance. However, many of the policies considered here were put in place for quite other purposes. It is not clear whether, or to what extent, they realistically can be regarded as instruments that might be consciously employed to influence innovation.

Put another way, the problem is this. Virtually every policy of government influences the climate for innovation in some way, in greater or lesser degree. For only a few is the influence on innovation a major factor considered in design and implementation of the policies. Which policies should be considered explicitly here? Presumably those whose influence is significant and whose design might be improved through evidence about the policy's impact on innovation. Unfortunately, evidence of magnitude of impact is hard to come by. Therefore, the focus must, and should, be on policies widely regarded -- whether correctly or not -- as having a significant effect and as subject to modification to make that effect more positive or less negative. Since the case studies contain relatively rich material on them, we shall focus on four such classes of policy: procurement; regulation; anti-trust; and patent and other policies affecting property rights on inventions. And we conclude this section by discussing why it may not be particularly fruitful to view most of these instruments as capable of playing a powerful role in policy packages designed for the express purpose of stimulating industrial innovation.

1. Procurement.

In undertaking its many and varied activities, the federal government buys a wide range of products. If one also considers the state and local government activities that the federal government helps to finance -- not to mention the regulatory and other objectives of government -- it becomes clear that the government is a direct or indirect purchaser of virtually everything. But the range of products for which the government has actively and consciously attempted to spur technological advances to enable it to achieve its objectives more effectively or in a less costly manner is actually quite limited. We argued above that there might be a high payoff to extending the range of such products considerably. Such an extension would enhance the capability of government to meet accepted public sector needs, while at the same time contributing to the advance of technologies for products sold and bought on commercial markets.

As the case studies show, there are a number of ways in which the government can attempt to draw forth technological advances. At one extreme, it can itself undertake or contract for virtually all of the R&D in the area. At the other extreme, it can advertise its interest in products with certain characteristics, and entice and support private R&D efforts through its procurement policies, with only limited direct public funding of R&D.

Much has been said about the role of government in "making a market" for certain kinds of technological advances -- usually with the implicit assumption that this is a kind of policy very different from that of government R&D support for the work leading to those advances. In fact, the distinction is actually quite a fuzzy one. Whenever the government tries to "make a market" for a new technology, it inevitably and appropriately will be drawn into some R&D support. Conversely, government R&D support of public-sector technologies does not make sense in the absence of aggressive procurement policies which, in turn, will almost inevitably induce certain privately financed efforts. In short, "making a market" for technological advances and R&D funding to facilitate those advances are closely tied together, with the mix of R&D inducement and R&D support a matter of tactics not strategy. Aggressive procurement is one aspect of a policy designed to draw forth better technologies that have both public-sector and non-governmental applications. Such procurement policies are a complement -- not a substitute -- for government R&D support policies in such areas.

2. Regulation.

If the reader approaches this study with any strong, simple ideas of the effect of regulation on technological change in industry, a reading of the case studies may quickly disabuse him of these. The studies reveal how diverse regulation is and how complex and subtle its influences sometimes are.

The automobile industry and, to a lesser extent, residential construction reveal what has been called "new style" regulation at work. (As the housing example testifies, new style regulation is not so new.) Regulation here amounted to the imposition of certain requirements on the products produced or the technology employed with the objective of assuring certain standards of quality, or safety, or protecting the environment, etc. However, regulation has had quite different purposes in the two cases, and has had different consequences for technological advance.

In the housing case, regulation has been conservative. Building codes and standards have stuck pretty close to prevailing techniques and materials, or simple modifications thereof. Far from being aimed at drawing forth new materials and methods, housing regulation has tried to monitor and screen these and, in fact, has made significant innovation expensive if not downright impossible. In contrast, regulation in the automobiles case has been used aggressively to pull forth new technologies. When the regulations were imposed, it was well understood that prevailing technologies could not meet the standards. One can argue about whether regulation was the most appropriate or efficient method to pull forth the desired innovations. White and other scholars believe that the route has been inefficient and expensive. Although this regulation strategy may have led the government to neglect direct R&D funding, it is certainly not the case that regulation has deterred innovation.

Pharmaceutical regulation is something else again. Originally concerned with maintaining purity standards and safety, in the 1960s regulation began to try to assure efficacy as well and to constrain and monitor the safety of the R&D process itself. There are very real questions about whether the post-1960s regulatory environment has actually increased the efficacy of the new drugs that reach the market or guarded the safety of patients and experimental subjects to any significantly enhanced degree. As Grabowski and Vernon argue, it is not easy to pin down and separate the effect of U.S. pharmaceutical regulation on the flow of new pharmaceuticals into the cornucopia. It is clear, however, that regulation has significantly increased R&D costs, and delayed the introduction of new drugs compared to the date of introduction in countries with different regulatory regimes.

The effects of new-style regulation show up less strikingly in the other industry studies. However, environmental and safety regulation has in recent years come to play a significant role in influencing the fertilizers and pesticides that farmers are allowed to use and, relatedly, the tests and hurdles a new agricultural substance must overcome before it can be introduced to the market. No study of the effect of such regulations on the flow of fertilizers and pesticides comparable to the studies of the effects of regulations on the introduction of new pharmaceuticals has ever been made.

In our case studies, civil aviation appears as the industry most strongly influenced by what has been called "old style" public utility regulation -- regulation aimed at constraining prices and requiring certain standards of service delivery. In this particular case, the airlines, while regulated, were in rivalrous competition with each other. Further, the industry doing most of the relevant R&D -- the airframe industry -- was not regulated. The consequences of regulation undoubtedly was to spur innovation.

As has been the case in other regulated but rivalrous industries -- for example, railroads -- regulation in the aircraft industry must be understood as setting floors under prices as well as establishing ceilings. In the airline case, the result was that, since rate competition was blocked on lucrative competitive runs, the airlines' competitiveness spilled over into the providing of better services and seats on more attractive aircraft. The consequence was that the airlines provided a strong, indeed eager, market for new aircraft. It has been often argued that old-style public utility regulation stifles innovation; this most emphatically was not the case here. This is not to argue that the regulation of air transport was a desirable policy from a social point of view or even that the stimulus provided by regulation for the development of transport aircraft was socially desirable. It simply is to warn against the simple-minded notion that regulation generally deters all kinds of innovation.

In view of the diversity of regulation and its impact, deregulation or regulatory reform means different things in different industries. For the airlines, it has meant the abandonment of rate regulation and the relaxation of CAB control on routes. While the new regime of aircraft competition may provide strong demand for new aircraft, it is hard to argue that the demand will be any stronger than it was under the old regulated regime, although the pattern of demand may be different. Airline deregulation is part and parcel of the deregulation movement for industries which, in the past, have been treated as public utilities despite the fact that their structure permitted considerable competition.

Reform of environmental and safety regulation involves a different set of issues and strategies. There is a movement nowadays to create regulation-setting machinery that will consider costs as well as benefits; toward using performance standards rather than prescribing particular technologies; and (in some cases) toward the use of fees or marketable licenses rather than quantitative restrictions. Such a reformed regulatory regime would quite likely provide a better, if not necessarily a stronger, environment for the generation of technological advances that respect environmental and safety values. However, what is needed here is more sophisticated regulation, not "deregulation." Unfortunately, much of the apparent thrust toward modification of "new style" regulation is toward abandonment rather than reform.

For the pharmaceutical industry, regulatory reform largely means simplifying and speeding up the evaluation procedures for new drugs. Grabowski and Vernon argue the current regulatory regime has significantly retarded and increased the cost of pharmaceutical innovation in the United States, and that the most effective available vehicle for spurring innovation is regulatory reform. However, of the industries studied in this report, pharmaceuticals probably is unique in this respect.

3. <u>Anti-trust</u>.

Just as with regulation, many people carry around in their heads an over-simplified and distorted view of what anti-trust has meant for technological advance. The case studies reveal quite complicated and varied stories.

The pharmaceutical and automobile industries have been traditional targets of anti-trust prosecution. Usually, however, the anti-trust cases have not involved innovation, or R&D, directly, but rather have been concerned with such old-fashioned matters as price fixing or other "conspiracies in the restraint of trade." In the pharmaceutical industry, a few of these have involved patent licensing and other related issues. However, neither the Grabowski and Vernon study, nor other studies of the pharmaceutical industry, have argued that anti-trust has had much of an influence on innovation in the industry, one way or another.

In the automobile industry, it is quite possible that concern about anti-trust action has deterred General Motors from being as aggressive technologically as it might have been. On a few occasions anti-trust has touched directly on issues relating to R&D and technological advance. The restrictions on patent pooling and on certain forms of cooperative R&D were noted in White's case study. The lawyers for the automobile company certainly had misgivings about what the anti-trust division would do if they joined the proposed Cooperative Automotive Research Program. However, present anti-trust guidelines, which permit cooperative R&D if the results are not treated as proprietary, would appear to leave room for programs of this sort and for most fruitful kinds of government-industry cooperative programs -- provided, of course, that the industry is persuaded that such guidelines are a suitable guarantee of future Justice Department behavior.

The computer industry is an interesting case for thinking through certain conundrums about anti-trust and industrial innovation. The history presented in the case study stops at just about the time that IBM achieved the dominance which it now has maintained for close to twenty years. As Katz and Phillips show, IBM was successful in part because it guessed right technologically and in part because it judged the market correctly. Other scholars have remarked that its previous dominance in the punch-card calculator business gave IBM a special advantage in the sale of computers to business users. Scholars and lawyers may argue whether it was technological leadership, shrewd judging of the market, effective marketing, taking advantage of old ties, or behavior subject to prosecution under the anti-trust laws that have enabled IBM to preserve its dominance in large scale civilian computers. Nonetheless, the anti-trust cases have involved, in an essential way, complaints about the way IBM goes about designing and introducing new computers, and the remedies proposed include some that would significantly limit the freedom of action of IBM regarding R&D and innovation.

The case studies reveal at least two striking instances where anti-trust and other structural policies preserved or created a competitive market structure with apparent salutary effects on industrial innovation. Although some scholars maintain that AT&T had no interest in going into production for sale of transistors anyhow, the 1956 consent decree legally foreclosed that option. The evolution of the semiconductor industry might have been different had AT&T decided to get into the commercial market. One might also note that the consent decree, while most visible in our semi-conductor study, stopped AT&T from going into <u>any</u> commercial market not directly connected with the telephone service. The evolution of the commercial computer industry might have been significantly different absent the restraints on Bell Labs and Western

Electric. As this report is written, Congress and the Administration are debating proposals to relax constraints on AT&T.[5]

A second example of government policies that influenced an industry's structure in a way that had a profound effect on technological advance is the revised Airmail Act of 1934. This Act broke up vertical integration among airlines, airline manufacturers, and engine manufacturers, and left a more open and competitive structure. Again, it is difficult to judge what would have happened if the industry had remained vertically integrated, but it is hard to imagine that technological advance would have been any faster than it was.

4. Patent and Related Policies.

How about public policies that affect patenting and, more generally, the ability of the company to appropriate the returns to an invention it makes? Again, the picture is mixed and complex.

In the pharmaceutical industry, it is apparent that the ability to patent a new drug is virtually essential if that drug is to be profitable for the company that creates it. Indeed, the whole history of the pharmaceutical industry would likely have been different had the courts ruled that antibiotics, as natural substances, could not be patented. However, in pharmaceuticals the question of the effective duration of a proprietary market hinges not only on patent life but on the decisions of physicians and pharmacists and on laws impinging on these decisions (e.g., regarding whether to prescribe and give out a "generic" or brand-name drug when the former is available). Arguments against generic

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5. See, for example, Ernest Holsendolph, "Senate Passes AT&T Decontrol," The New York Times, October 8, 1981, p. A-1.

prescription are, in effect, arguments that protection provided by a patent ought to extend beyond its legal limit. Of course, the effective life of a patent in the pharmaceutical industry depends on the relationship between the date of patenting and the date of commercial introduction of the product. The testing and licensing requirements mean that there is often a very considerable lag between patent application and commercialization. Returns to invention in the pharmaceutical industry clearly depend on a wider set of variables than the strength of the patents.

For many of the other industries studied, legal protection of proprietary rights seems to be less important than in pharmaceuticals. Key patents have played a role in the evolution of mechanical machinery in agriculture, and in inducing new chemical compounds like fertilizers and pesticides. However, while hybrids were judged patentable, it is not apparent that a patent adds much to the protection a seed company has for its particular hybrid. A potential competitor cannot really discern the exact nature of that crossing that led to the particular hybrid seed. In this case the patent may be a minor rather than a major element in assuring appropriability.

In semi-conductors, while firms patent their new devices, these patents do not have much force. Sometimes producers of new devices are able to hide their design from potential competitors by "potting." But in this industry imitation is generally quick. Indeed, the insistence of government and other purchasers of semi-conductors on "second sourcing" requires in effect that a firm's new design be produced by another firm as well as the innovator. The profits to a successful innovator in this industry would appear to reside largely in the head start that provides a short period during which the innovating firm is the sole supplier and an ability to move down the learning curve before other firms get into production.

With a few interesting exceptions, patents appear not to have played a particularly important role in inducing, or making profitable, innovation in automobiles or civil aircraft. Indeed, in both industries there has been a tradition of relatively easy patent licensing, or even patent pooling. The reason for the lack of interest in a particular patent would appear to be that automobiles and aircraft are complex systems, and that particular patentable components do not really play much of a role in determining the attractiveness of the overall system. It is the general overall engineering of the product that counts, and that is not readily patentable. Much the same situation seems to apply in computers. While patent suits marked the early history of the industry, IBM's prominent position does not rest on its patent holdings.

5. <u>General Purpose Instruments, More Generally</u>.

It would be easy to draw on the case studies and other material to extend the list of government policies that influence the climate for industrial innovation. Some of these policies are broad in scope, although their influence differs from industry to industry. While the influence of the tax code is pervasive, particular features, like the treatment of capital gains, appear to be particularly important to certain industries. Thus it has been argued that the higher taxation of capital gains that came with the tax bills of the early '70s had an especially strong negative effect on funds to finance innovation in the semi-conductor industry. It is unlikely that these statute changes had a comparable effect on aviation. While monetary policy is cross-cutting, our particular monetary institutions segregate the housing industry and make that industry bear the brunt of the economic fluctuations to a great extent. Some policies are aimed at particular industries. Special price support programs certainly have influenced technological advance in agriculture. The trade agreement with Japan regarding the importation of television sets especially affected the U.S. semi-conductor industry. One could go on. However, if our search is for instruments that can be considered powerful tools for a policy to stimulate industrial innovation, such extended listing and analysis is not likely to be fruitful. There are several reasons.

First, the broad policies in question have been put in place for a variety of reasons. Arguments about their effect on industrial innovation will carry only limited weight in influencing the debate about their reform. This is not to say that such arguments have no influence. A tax credit for R&D was proposed by several groups as an important instrument to spur innovation, and such a tax credit was part of the recent Reagan tax modification package. But an R&D tax credit was only a small part of that bill, and it is unlikely that the particular proposal would have been heeded had there not been a general thrust toward tax reductions of various kinds.

Second, the broad policies in question often differ in the particulars of their application from sector to sector. Therefore, it is virtually impossible to identify any general rules for reform of any of these instruments for the purpose of spurring industrial innovation. Rather, the most salient proposals would appear to be industry-specific -- for example, particular reforms of pharmaceutical regulation.

Third, while undoubtedly in some cases there is a tradeoff between stimulus of industrial innovation and other policy objectives, our perusal of the case studies suggests that, in most instances, the reforms that make sense as a stimulus to the right kind of innovation makes sense in terms of more general criteria as well. Thus, while regulatory reform is not a broad panacea for stimulating faster or better-directed technological advance, the kinds of reforms that scholars long have proposed on grounds of general economic efficiency for pharmaceutical regulation and auto emissions control probably would affect innovation in the right direction. Our case studies reveal a few instances where anti-trust may be acting as a restraint on certain types of industrial innovation, but they certainly provide no general indictment of anti-trust policy on these grounds. The anti-trust issues involved in the suits against IBM or AT&T are complicated. As a general rule, however, it does not appear that anti-trust is hobbling innovation by business. Similarly, there appears to be no general magic in reform of the patent law or in the patent policies of particular government agencies that fund R&D.

Let us not be misunderstood. It may well be that establishment of a generally supportive climate for industrial R&D is the most important thing the government can do to facilitate industrial innovation. We would put particular stress on the importance of strong aggregate demand, relatively stable demand growth, and predictable prices.

When business conditions are good, and incomes and demand are growing rapidly and predictably, business firms can anticipate an expanded market and make their investment and R&D plans accordingly. When demand is stagnant -- or uncertain -- investment in new plant and equipment is deterred, and R&D aimed to tap new markets may look like a very risky proposition. Of the industries studied in this report, housing is the one that is most noticeably influenced by changing macroeconomic conditions. Quigley and others have argued that the cyclical sensitivity of residential construction is an important factor explaining the structure of the industry and the limited incentives for innovation associated with investment in durable equipment. However, virtually all industry is subject to some cyclical influences. The demand of farmers for new agricultural implements is cyclically sensitive. A non-trivial proportion of the demand for semi-conductors is cyclically sensitive. Economic slumps hurt the airlines, diminish their ability and incentive to invest in new equipment, and reduce returns to the design and development of new aircraft.

However, even if there were no effects on innovation, it would be the objective of macroeconomic policy to achieve a sustained growth, high employment, steady prices. As with regulatory and anti-trust policy, the objective of stimulating innovation carries no particular implications for fiscal and monetary policies.

It seems to be like this in general. If the specific interest is in stimulating innovation, it is a mistake to look largely to general-purpose policies. The design of them can be influenced only marginally by concerns about innovation, and often concern for innovation does not point to departures from policies that are sensible on more general grounds. If "innovation" policy is to have any meaning, search for one must be focused on more specialized instruments.

D. A Brief Summing Up.

In the preceding section, we identified a wide range of government policies that defined the climate, influenced incentives for, and imposed constraints on industrial research and development. In virtually all of our case studies, one or more of these government policies was an important part of the story. However, the most important such policies differed from industry to industry. While it is apparent that a number of specific reforms might have significant benefits, the case studies do not seem to reveal any general and powerful guidelines for regulatory or antitrust or patent policy reform. If a serious mandate re-emerges to find and implement government policies that will significantly spur industrial innovation, debate should try to avoid the understandable temptation to look to modifications in these general instruments to do the trick. There isn't much leverage there. Moreover, the kinds of improvements in macroeconomic and other policies that make most sense for stimulating the right kind of innovation make good sense in terms of other criteria as well.

If government must look specifically for policies that may have a significant stimulating effect on industrial innovation, the place to look is in the bag of R&D support policies. This chapter has not attempted to give a general rationale or justification for active government support of R&D nor to draw up fine theoretical arguments to guide such policies. A decade or so ago, economists had much clearer and more pointed theoretical views about these matters. The externalities from R&D and the uncertainties involved led, according to the theoretical perspective prominent at that time, to a divergence between the quantity of R&D expenditure that firms would find most profitable and the quantity that was optimal from a "social" point of view. The firms would spend too little. Public support or subsidy therefore was warranted and ought to be focused on those kinds of R&D and on those industries where the externalities and the uncertainties were the greatest. Subsequent theoretical work has led economists to draw a more complicated picture. A competitive regime in which firms gain property rights on certain of their technologies draws forth some R&D that is socially wasteful. Major technological uncertainties call for a variety of approaches with open knowledge of routes being explored and what is being found along the way, and not a big push along one particular road. The problem with market-induced industrial R&D allocation lies in the portfolio -- the allocation of resources -- rather than in a total magnitude of effort.

But if the problem is not simply characterizable as "too little" research and development, the design of appropriate government policies requires mechanisms to identify the particular kinds of research, and sometimes the particular projects, that are being under-funded. Therein lies the problem. Government agencies are seriously constrained in the information they are able to marshal directly or indirectly to guide the allocation of public R&D monies.

The historical experience canvassed in this study suggests that there are three routes that can be followed. One is to associate government R&D support with procurement or another well-defined public objective. A second is to define and fund arenas of non-proprietary research and allow the appropriate scientific community to guide R&D allocation. The third is to develop mechanisms whereby potential users guide the allocation of applied research and development funds. A fourth kind of policy, in which government officials try themselves to identify the kinds of projects that are likely to be winners in a commercial market competition, is seductive -- but the evidence collected in this volume and other studies suggests that it is a strategy to be avoided.

These are qualitative judgments drawn from qualitative and impressionistic case studies. While we can provide some reasoning to make them plausible, we can provide no tidy and powerful general theoretical justification for them. Perhaps the lesson that economists should draw from their earlier attempts to base prescription for government R&D policy on theoretical arguments is that this is a dangerous game. Economic reality is too complicated to be fit well by any simple theory. More complicated theories generally point in different policy directions, depending on the quantitative magnitude [illegible] in key parameters. The design of good [illegible] empirical research, and not simply on [illegible] reasoning.

There are two major weaknesses with the evidence provided in this study supporting the above propositions about policies. First, the evidence comes largely from studies of seven U.S. industries. Second, the evidence is qualitative and judgmental, not quantitative and readily verifiable.

This first weakness is not as serious as it might seem, although this study would have been enriched had coverage been wider. There are available a number of other industry studies, some of the United States, some of Europe. There are also several across-the-board evaluations of government policies in support of industrial innovation, particularly policies of European countries. The conclusions drawn in this chapter were influenced not only by the case studies but also by this other evidence, and are consistent by and large with both bodies of data.

The second weakness is more serious. One can try to avoid having to base conclusions largely on qualitative and impressionistic evidence by constructing formal models and hypotheses and estimating and testing these with statistics. To some extent this kind of work has been done for agriculture. But such quantitative conclusions are no better than the models and the data on which they are based, and these contain large elements of the subjective and judgmental.

We are more concerned about the faith that lay persons, policy makers, and even scholars often show in quantitative conclusions drawn from shaky models and data than about conclusions that are explicitly qualitative and judgmental. When our knowledge is stronger, when we understand things well enough to have confidence in the basic form of the models we write down, when we have data that are more conformable with our operating models than they now are, then quantitative studies can play a greater role. We would argue, however, that, at the present time, the most promising route towards such stronger knowledge is to pursue case studies of the sort reviewed here and the kind of qualitative, judgmental analysis developed in this chapter.

IV. RECENT FEDERAL INITIATIVES IN CIVILIAN SECTOR.

The last chapter examined the history of technical change in U.S. industry and tried to draw from that history lessons for government policy. This chapter looks at the more recent history of several policy initiatives for boosting civilian technology -- with an eye toward analyzing these programs in light of the lessons from our case studies.

We focus primarily on three programs proposed or active under the Carter administration -- the Cooperative Generic Technology Program (COGENT); the Cooperative Automotive Research Program (CARP); and the industrial energy productivity program in the Department of Energy (DOE) -- that have been eliminated under the new administration.[1] We also discuss more briefly some National Science Foundation efforts that remain in operation.

Each of these programs has features the reader of the last chapter will find familiar; there are a few novel features as well. Evaluation in any strong form is difficult (even for the DOE program which, unlike the other two, was a functioning, and not merely an incipient, program); but we hope to be able, nonetheless, to draw a few tentative conclusions along the way about the programs and their effectiveness.

The discussions of the programs presented here -- their history, objectives, rationale, and methods -- are based primarily on published reports. But our analysis has also been

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1. On the Reagan administration view of policy toward civilian-sector R&D -- and on the demise of COGENT in particular -- see Arlen J. Large, "A 'Monument' Industry Innovation Law Crumbles Under Reagan Administration," The Wall Street Journal, July 15, 1981, p. 34.

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informed by interviews with both federal officials and industry representatives, whose ideas and views were aired during three meetings we held with senior executives from all phases of the R&D enterprise. The first meeting (on November 30, 1979) looked to government officials involved in civilian-sector R&D; the second meeting (on February 22, 1980) sought primarily the industry perspective. The third meeting -- significantly, on October 29, 1980 -- brought the two groups together. That meeting's format consisted of presentation by senior federal officials of five programs of government involvement in civilian-sector R&D. An audience that included many executives from the private sector provided comments and raised questions.

A. The Cooperative Generic Technology Program.

COGENT was an outgrowth of assistant Commerce Secretary Baruch's 1979 Domestic Policy Review on innovation. The program was announced on October 31, 1979, as part of what was described alliteratively as the "President's Industrial Innovation Initiatives."

Like their precursors in earlier administrations,[2] the Carter initiatives -- and COGENT in particular -- were intended as (an at least partial) cure for a "lag" in U.S. technological innovation -- and, by implication, for various macroeconomic problems. "Increased industrial and technological innovation," as Congress found and declared in the legislation authorizing COGENT, "would reduce trade deficits, stabilize the dollar,

2. Cf. Section II.A. above.

increase productivity gains, increase employment and stabilize prices."[3]

The key feature of this program, of course, was its focus on "generic" technologies. As such, COGENT arguably represented an intellectual advance over earlier schemes to boost innovation.

The program's operating regulations suggest cautiously that government involvement in generic technologies is indicated whenever cooperation within the private sector alone is "inappropriate";[4] and the Congressional committee report is explicit that "'generic research,' like basic research, is not likely to attract funding from individual firms because they cannot capture the benefits directly."[5] Yet, an interest in the "generic" -- in technologies that cut across and might prove fundamental to several industries -- suggests a somewhat richer understanding of the process of technological change than is implied in most externality arguments. Innovation is not simply a matter of mechanically pumping "sufficient" or "adequate" amounts of R&D funding into an existing firm or industry and expecting it promptly to produce a proper level of productivity growth. Technical change is in fact an immensely complicated process in which technologies connect together in often

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3. S. 1250, 96th Congress, 2nd Session, Section 2, Paragraph 6. Called the Stevenson-Wydler Technology Innovation Act of 1980 -- and now zero-funded under the Reagan administration -- this bill gave the Congressional stamp of approval to COGENT, even though the Carter administration had planned to go forward with some form of generic technology program anyway under existing legislative authority.

4. COGENT Regulations, 15CFR17a, published in the Federal Register, vol. 45, no. 159, August 14, 1980, p. 54029.

5. U.S. Senate, Committee on Commerce, Science and Transportation, report no. 96-781, May 15, 1980, p. 8.

unexpected ways and in which firms -- and entire industries -- occasionally appear and disappear.

In particular, advances have often been most dramatic when, in a kind of space-warp across the industrial structure, a technology developed in one industry suddenly becomes applicable to a previously unsuspected wider range of industries. This is often called "technological convergence."[6]

A program of generic research, under this interpretation, is an attempt to anticipate and cash in on such convergence. The government, therefore, is not engaged in the business of "picking winners" -- whether firms, industries, or projects within an industry -- in a specific or detailed way. Of course, the government must somehow pick "generic winners," and this may not be as easy as suggested by COGENT program documents, which assert with a confidence bordering on epistemological hubris that "a study of generic technologies can identify latent technologies yet to be invented (or those which are in use in one industry but are candidates for application in other industries) or promising new industries which do not yet exist."[7]

Selecting generic technologies was in fact the first step in the COGENT process. The Commerce Department engaged the Industrial Research Institute Research Corporation, an industry group, to study nine potential areas of generic

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6. See Nathan Rosenberg, Perspectives on Technology, Cambridge: Cambridge University Press, 1976.

7. U.S. Department of Commerce, Office of Cooperative Technology, "Cooperative Technology Program: Key to Industrial Innovation," Revised Draft, January 24, 1980, p. 2.

technology.[8] The group was charged specifically with determining not only the technical and economic benefits likely from pursuing each technology but also the willingness of industry to cooperate in each area. Based partly on this report, the Commerce Department at the time of COGENT's demise had settled on -- and was beginning to set up projects on -- three areas: powder metallurgy, welding, and friction (or "tribology"); two other areas under consideration were artificial intelligence and something called "near net-shaped processing."[9]

The institutional structure of COGENT was to have been built around "Generic Technology Centers." Each center was to have been an independent entity which, although perhaps affiliated with a university or other institution, would nonetheless have required its own charter and by-laws as a non-profit corporation. Industrial firms who wished to participate in the research were to become members of the center; each firm would send a representative to the center's board of governors, and each would be assessed dues according to a formula considering such factors as the member's size and the directness of its interest in the research.

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8. Industrial Research Institute Research Corporation, "Cooperative Technology Program: Evaluation of Nine Candidate Areas for Industry Participation and Support," Revised Version, December 10, 1979. The nine original areas studied were: automated watch manufacturing; composite materials; welding and joining; textiles; powder metallurgy; organic coatings; semi-conductors; radiation processing; and corrosion. Of these, only powder metallurgy and welding were in COGENT plans at the time of the program's demise.

9. Comments by Lansing Felker, assistant director of COGENT, at our October 29, 1980, meeting.

The principal function of a Center was to have been the performance of "in-house" generic R&D. The program regulations are insistent that most of the research be conducted "in-house" in order "to take advantage of cumulative research and problem-solving expertise."[10] The research agenda for a Center would have been set by its board of governors, with an expectation that the projects chosen be relevant to the Center's generic technology and promise results significantly outweighing costs.

Centers were to have other functions as well. One of these was the provision of technical services, comprising consulting services; information systems and data library services; training; and "technology evaluation" to monitor progress in the generic technology. (The program regulations emphasize that the consultation services must "complement" and not compete with private consulting services; it's far from clear what this would -- or should -- have meant in practice.) A center was also to maintain a "strategic planning" capability to guide the progress of its research agenda.

One interesting provision of the program regulations stipulated that Center membership "may not be conditioned upon adherence to agreements which unreasonably restrain trade."[11] This was interpreted to mean that firms could not be required to sign, as a condition of Center membership, agreements restricting them in their use of technical information -- or patents -- developed at the Center; in their use of technology developed elsewhere; or in the research they themselves conduct outside the Center. The regulations also provided that the Center disseminate its findings to members

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10. COGENT Regulations, Op. Cit., p. 54029.

11. COGENT Regulations, Op. Cit., p. 54031. (15CFR 17a8(b) (2)(iii).)

at reasonable cost without discrimination; and they left the matter of dissemination to non-members up to the discretion of the Center's board, with a proviso that "no significant anticompetitive result ensue from such decisions."[12]

COGENT plans called for a mix of government and industry funding. The first-year budget was to have been $5 million. Planners viewed this contribution as "seed money," though, and anticipated phasing out government support within five years, thus requiring each Center to become self-sustaining on members' dues, contract research, and consultation revenues.

Although the program would have had in the end to stand or fall on empirical grounds, the program's design had much to recommend it on theoretical grounds.

* The notion of keeping COGENT centers independent of universities might have had the effect of establishing a healthy tension between the basic and applied. (Cf. the case of the NACA research center in the early aeronautics industry, as well as the system of sequestering agricultural and medical research in professional schools outside mainline university research departments.)

* The idea of requiring most research at a COGENT center to be conducted "in-house" -- thus helping to develop a "memory" for the generic technology -- is consistent with the (desirable) objective of developing a strong scientific base in the field.

* The system of center membership by interested firms and the guidance of research by a board of directors representing those members suggests a structure that, despite initial resistance, might ultimately have led to a successful working relationship with the private sector.

Whether COGENT would have been effective -- let alone desirable -- is probably not a question whose answer could be known in

12. Ibid. (15 CFR 17a.8(b)(2)(v).)

advance of actually trying out the program. Of all the lessons to be learned from the agricultural example, perhaps the most important is that a successful institutional structure comes about through a slow process of adaptation, aligning the interests of the various groups one with another. There is a suggestion in the COGENT planning documents that program planners were aware of this. Many of the parameters most crucial to the outcome of this adaptation process -- notably the proprietary structure and patent policies of the Centers -- were left unspecified in the regulations.

In other areas, it is less clear that COGENT learned all the lessons of history. For example, there is no _a priori_ reason to suspect that the "externality" problems COGENT was supposed to correct would have cleared up in time for a Center to become self-sustaining after five years. The agriculture example suggests that continued government funding may be a key to success; and the NACA example suggests that, were the "externality" to be conquered, it might instantly obviate the existence of the COGENT Centers.

B. The Cooperative Automotive Research Program.

The auto industry in recent years has become emblematic of the sort of industrial "lag" that motivates programs for boosting civilian technology. In December, 1978, a time when the problems in the American car industry were very much on the public mind, then-Transportation Secretary Brock Adams suggested at a much-publicized news conference that the government ought to enter into a massive effort to "re-invent the car."

What emerged from the resulting furor in Washington and Detroit was CARP, a program whereby industry and government would jointly fund basic research on automotive-related technologies.

The Carter administration held a conference in February, 1979, attended by some 700 scientists and engineers, to talk about directions for basic automotive research. Then, in May, 1979, Carter met at the White House with the heads of the domestic car companies to discuss the principles of what became CARP.

Under CARP -- which has been entirely dismantled by the new administration -- the government and the car makers would have jointly funded research projects in twelve general areas: combustion, thermal, and fluid sciences; structural mechanics; electrochemistry; aerodynamics; materials; control systems; tribology; acoustics; surface science and catalysis; environmental science; biomedical science; and behavioral science. The administration had worked up a lengthy research agenda in each area based on advisory reports from a team of industry, university, and government scientists.[13]

CARP was to be a "50/50 sharing arrangement." But it would not have involved joint or cooperative research in a literal sense. Auto companies were independently to fund basic research projects, which could take place "in-house," in university labs, or in government facilities as each company saw fit. For all such projects deemed "countable" by a CARP Oversight Committee (in light of the aforementioned twelve categories), the government would have funded -- equally independently -- a matching amount of research whose type and location would have been at government discretion. Program

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13. This report was published in The Congressional Record, Senate, September, 1980, pp. S12813-S12834.

planners described the approach as "decentralized" and "pluralistic."[14]

The $12 million slated for the first year of operation had included no contribution from the private sector; but program planners had hoped to "ramp up" to $100 million per year in three to five years, with half of that coming from the domestic auto makers.[15] Each manufacturer was to have been assessed an amount in proportion to its market-share.

The Department of Transportation was to have been the lead agency for CARP, allocating 60 percent of the government research funds; the National Science Foundation was to have control of the remaining 40 percent.

As of November, 1980, four domestic auto makers -- Ford, Chrysler, American Motors, and Volkswagen of America -- had agreed to participate. General Motors was somewhat recalcitrant. Since a CARP without GM would have been a bit like Hamlet without the Prince, this created problems from the start. GM's reasons for discontent are unclear, but seemed to involve uncertainty about antitrust implications and skepticism about the program's ability to allocate technical resources effectively. It was equally unclear as to whether GM's hold-out was intended merely to maximize its influence on the shape of a program it expected ultimately to accede to -- a strategy perhaps involving the suspicion that Jimmy Carter would not long remain in office -- or whether GM had no intentions of ever signing on.

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14. See, e.g., testimony of Philip M. Smith, Associate Director of the President's Office of Science and Technology Policy, before the Senate Subcommittee on Science, Technology and Space, April 30, 1980, p.5.

15. Op. Cit., p. 12.

As was the case with COGENT, the Justice Department and the Federal Trade Commission gave their assurances that participation in CARP would not plunge a firm into antitrust difficulties.[16] Patent provisions for the fruits of CARP-sponsored research were never fully worked out, although the basic research character of the program made these concerns somewhat less pressing. CARP planners articulated the principle of "wide and open dissemination of results to all interested parties subject to the appropriate patent provisions."[17]

Although also aimed at "generic" technologies in some sense, CARP was a program with far less institutional detail than COGENT. Indeed, it seems to harken back to earlier approaches to stimulating industry through R&D, implicitly suggesting that the problem in the car industry stems from an "insufficient" level of basic research by car firms. Except for specifying a review board to pass on research projects, the design of CARP was almost studiously non-institutional in character; and one might almost be forgiven for applying to CARP the uncharitable cliché that it intended merely to "throw money at the problem."

Those who would contemplate similar efforts in the future might well wish to create a structure somewhat closer to the COGENT model.

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16. Op. Cit., p. 9.

17. Op. Cit., p. 5.

C. <u>The DOE Industrial Energy Program</u>.

The DOE industrial energy productivity program[18] was similar to COGENT in that it was concerned at least in part with "generic" technologies -- in this case technologies that could be applied to save energy in a number of industries. The program differed from COGENT (and CARP) not only in that it was an operating program at the time of its demise[19] but also in that it did not confine itself merely to directed basic research.

Part of President Carter's National Energy Plan, the industrial energy program was intended to speed the introduction of energy-saving technologies in industry. The program operated on the theory that, although increased energy prices had already spurred industry to a 9.7 percent average efficiency improvement between 1972 and 1976, all the easy solutions had been exhausted; future results "would depend principally on larger capital investments and major process changes."[20] The DOE approach to this perceived problem was to contribute government funds to commercial research, development, or demonstration projects to develop new energy-saving technology.

The program had two principal thrusts. The first, which could be described as "generic" in focus, was toward "wide-application projects." Such projects were to "improve the energy efficiency of processes and equipment that are common

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18. The full correct title is the Federal Industrial Energy Conservation Research, Development, and Demonstration Program.

19. The program was zero-funded under the Reagan budget.

20. U.S. Department of Energy, Office of Conservation and Solar Applications, <u>The DOE Industrial Conservation Program: A Partnership in Saving Energy</u>, Washington, D.C., no date, p.6.

to many industries."[21] Examples included waste-heat utilization (e.g., high-temperature recuperator systems, industrial heat pumps, etc.); alternative materials (e.g., coal as a feedstock for acetylene); and advanced cogeneration. The second thrust was toward "industry-specific projects," which were intended "to increase the efficiency of processes used by the most energy-intensive industries, and to achieve the substitution of abundant fuels for oil and natural gas in these industries."[22] The target industries included steel, aluminum, glass, and cement (high-temperature processes); textiles, paper, and general product manufacturing (low-temperature processes); and agricultural and food processes. The program also boasted a third and more vaguely defined thrust -- "technology deployment" -- which involved planning for the market penetration of new technologies.

Although the program's literature is littered with what are fairly dubious justifications for government involvement -- e.g., that "capital is scarce" or that firms tend to weigh a dollar saved on energy equally with a dollar saved elsewhere[23] -- the program ultimately rested its justification on fairly solid economic ground -- or on what, at any rate, was regarded a few years ago as solid ground. The basic notion was that DOE should contribute public funds to an R&D project only when the project would otherwise be "too risky" for a private firm to undertake unaided. More precisely, they implicitly argued that social rates of return may diverge from private rates because a firm is risk-averse whereas society as a whole should be risk-neutral; therefore, government

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21. Op. Cit., pp. 16-17.

22. Op. Cit., pp. 17-20.

23. Op. Cit., pp. 7-8.

should get involved whenever risk-aversion is suspected.[24] This philosophy of intervention was formalized by DOE in a computerized project-selection technique,[25] which calculated the expected return and riskiness of each project; DOE would fund only projects with an acceptable rate of return whose riskiness placed them outside the domain of likely private sponsorship. The probabilities employed in this procedure were estimated by DOE on the basis of technical, commercial, and institutional factors. Each applicant was also required to assert that it would not have carried out the project in question in the absence of government assistance.

The program included no provision for the beneficiary of the R&D support to repay DOE in the event of a successful project. The federal share in projects was typically 30 percent. Program budget obligations were $21.7 million in fiscal 1978 and $36.3 million in 1979. The program's goal was a 3.2 quadrillion Btu/year energy saving in 1985.

Like CARP, the DOE program was also arguably based on an older model of government intervention, one which, despite its partial focus on the "generic," ultimately involved the government in "picking winners" and evaluating particular research projects. Nonetheless, the DOE program seems by all indications to have been an effective program, in that it was embraced and utilized by the private sector.

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24. The economic models from which this risk-aversion argument derive are closely related in form and assumptions to the appropriability-externality models discussed in Section II.C. above. See especially Kenneth Arrow and Robert Lind, "Uncertainty and the Evaluation of Public Investment," American Economic Review, June, 1970.

25. See U.S. Department of Energy, Office of Conservation and Solar Applications, "Industrial Energy Conservation Program Project Evaluation-Threshold Analysis." Washington, D.C. mimeo.

A primary reason for the program's success seems to be its concentration on process innovation, which limited the uncertainties primarily to technological and engineering-economic -- as opposed to commercial or marketing -- areas. Competent management and a low profile were undoubtedly important ingredients as well.

D. The National Science Foundation Programs.

In the years immediately after World War II, some 12 percent of university research was funded by industry. The figure today is closer to 3 or 3½ percent (although it is increasing). This signals a breakdown in communication between business and academe, according to Dr. Jack Sanderson, Assistant Director for Engineering and Applied Science at NSF.[26] (This directorate has since been renamed the Engineering Directorate.)

In 1972, NSF began establishing industry/university cooperative research centers. Examples in operation include the polymer center at MIT, the "submicron" center at Cornell, and the rather ill-fated furniture center in North Carolina. The main difference between these centers and those proposed for COGENT seemed to be that NSF centers are affiliated with universities.[27]

A slightly different kind of center funded by NSF is an "innovation center" aimed at teaching entrepreneurial skills to engineering students. There is evidently a project

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26. Remarks at our October 29, 1980, meeting.

27. For a fuller discussion of NSF's cooperative research program, see Neal H. Brodsky, Harold Kaufman, and John Tooker, University/Industry Cooperation, New York: Center for Science and Technology Policy, 1980, pp. 34-41.

along these lines in operation at the University of Utah.

NSF also retains a small-business project, in which firms with an innovative idea in need of development can receive support. An important requirement of the program is that applicants have venture capital already lined up to finance the developed idea if it proves successful.

NSF was also to have been involved in the CARP program (it was to allocate 40 percent of the funds initially), lending its expertise in university research matters to the Department of Transportation, which was ultimately to have taken full charge of CARP. Another NSF venture is a project to refit the infamous Glomar Explorer for experimental oil drilling in the deep ocean and Continental Margin areas. Sanderson also mentioned projects in robotics and fluid-bed combustion.

Another part of NSF attempting to increase communication between the academic and the industrial is the Joint University-Industry Research Program. Frederick Betz, who heads the program, described himself as a sort of "banker" with a pot of money for research projects jointly undertaken by university and industrial scientists.[28] The procedure is this. A proposal involving joint efforts of both industry and university is submitted to the segment of NSF appropriate to the project's topic; the proposal then undergoes peer review; successful proposals then go to Betz for funding under this program. (NSF funds only the university share; industry picks up the tab for its researchers.): This is now being changed.

The program was funded at a level of $5 million in FY78, increasing to $7 million in 1979. Unlike CARP, COGENT, and the DOE industrial program, the NSF programs were not cut completely by the Reagan administration.

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28. Remarks at our October 29, 1980, meeting.

V. CONCLUDING COMMENTS ON MAJOR THEMES.

What type of conclusions does one derive from a study based largely upon anecdotal experiences and judgments?

A number of important themes have emerged from our study of recent federal initiatives, from a number of the industry studies, and from the comments of industry and/or government executives. They have surfaced in the analyses of both government science policy and industrial research. Thus, a primary type of "conclusion" is the identification and significance of these important themes, placed in a perspective that permits us to take them into proper account for the formulation of future policies and the initiation of future programs.

There is a second type of "conclusion" one can draw from these common themes and from the anecdotal data of this study. We can set down statements about the interactions of public and private sectors that appear to characterize desirable or effective relationships for federal support of civilian R&D -- statements that can serve as criteria to guide future actions.

The perspectives derived from this study consist of a number of fairly simple principles or observations drawn from the evolution of, and recent experiences in, public- and private-sector interactions, along with evaluations of the several principal themes. We will therefore consider the general principles that apply to the present status of civilian-sector R&D as one theme, and address separately the other individual topics, although some of the general principles will refer briefly to subjects discussed more fully as specific themes.

A. General Principles for Public- and Private-Sector R&D Interactions

It is important to state first those aspects of the civilian-sector R&D structure that are most critical to the effectiveness of federal activity. Every Western industrialized country has developed a pattern of government involvement in civilian-sector R&D. But there are two factors which, taken together, apply to the situation in the United States to a far greater degree than to the other countries of the OECD (Organization for Economic Cooperation and Development):

1. The private sector has the responsibility in almost all areas, subject to boundary conditions set by government, for the manufacture and distribution of goods and services for the civilian sector. It thus has the primary responsibility for investment and marketing decisions related to the exploitation of technical change.

2. Industrial research funded by the private sector constitutes a very sizable resource in absolute terms ($33.9 billion in 1981) and as a percent of the total national R&D expenditures (49 percent in 1981). The amount of R&D conducted within industry -- both industry and government-supported -- is far more substantial ($49.2 billion and 71 percent of the total in 1981).[1]

We therefore have a picture of the private sector in the U.S. as relatively self-sufficient in its ability to generate the R&D it requires for growth. The industrial research conducted within the private sector is surrounded by a wealth of technical activities throughout the world that are not necessarily intended for its support, and by a number of federally-funded activities that are. The linkages through which the private sector extracts benefits from this broad technical reservoir are generally loose and informal,

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1. Willis H. Shapley, et. al., eds., Research and Development: AAAS Report VI, Washington: American Association for the Advancement of Science, 1981, p. 87.

based more on professional interactions than on mechanisms set up for deliberate exchanges.

It is in this broad context that we must consider the actions of the federal government and the reactions of the private sector. When we consider federal support of civilian-sector R&D, there is the implicit assumption that the technical activity supported is expected to be converted to use, i.e., it will be integrated by some mechanism into the operations of the private sector, emerging in the form of new products, processes, and services.

This is why the question of improving the effectiveness of federal support for civilian-sector R&D turns upon the more fundamental question of whether the federal government should engage in a specific area, particularly when the private sector is relatively self-sufficient and must balance technical change with financial and marketing resources. Given the implicit desire for conversion to use, an action that should not be engaged in by the federal government by this judgment will very probably not turn out to be an effective action. That, in fact, is a principal historical observation emerging from the analysis of industry and individual experiences during this study.

This provides a working model with which to extract some general principles from the material assembled in this study. Federal support of civilian-sector R&D must develop appropriate linkages with the private sector so that our economy can derive the benefits from that support. On this basis, we can now set down a number of general principles illustrated by these materials.

* The economic basis for government involvement in civilian-sector R&D should be seen as involving more than merely an assessment of the "social returns" to various levels of R&D funding.

Economic theory in recent years has begun to realize that the process of technical change in industry is a complex one, and that the rationale for government involvement is more than a simple matter of the sufficiency or insufficiency of private R&D funding. The important problem -- economists are increasingly recognizing -- is the identification of which technologies and types of projects are insufficiently supported by the private sector. And programs for government involvement in R&D thus must be attentive to the mechanism proposed for the allocation of federal resources to R&D.

* There must be widespread support for the need for a federal role in supporting a specific program of civilian-sector R&D.

This is the common-sense doctrine stated at the beginning of this section. For any proposed policy of action, there must be a logic as to the propriety for the particular action by the federal government. Further, there should be a reasonable agreement as to this need on the part of all interested parties.

* Technical change in almost every industry sector can be influenced by some federal action.

There is not, and has not been, a neat separation between the private-sector pursuit of technical change and the actions of the federal government. The amount of federally funded R&D conducted by each industry may vary, but this is not the main principle at issue here. The point is that the range of federal actions, including procurement and tax policies as well as the direct support of R&D, is so wide that it has been a factor in technical change throughout industry at many times in our history. The image of an industry planning, conducting, and exploiting all the technical change it requires independently of any interaction with the federal government is not a realistic picture of the actual growth of U.S. industrial technology.

* Effective federal R&D involvement is related to a federal role as user or supplier.

Selecting the highest-priority research programs, setting the most realistic objectives, and integrating the results in the manufacture and use of a product or process -- all of these functions are expedited by some familiarity with product specifications or market needs. The familiarity is possessed by those who buy and use it. Thus, the outstanding successes of federal R&D activities during and after World War II were in those fields in which the federal government itself was the customer.

* Support for civilian-sector R&D should be industry-specific.

The varying characteristics of each industry (cf. Chapter II.B.) define the relative importance of technical change in the growth and competitive relations for that industry. They also indicate which category of research may be lacking, whether there is a role for government to fill a void, and whether the capabilities and opportunities for exploiting technical change are present. The use of direct or indirect instruments of government support will depend critically on these characteristics. Federal support for R&D in the metal and mining industry, for example, should be radically different from any such support in microelectronics.

* Federal R&D activity is most effective and least controversial in strengthening the infrastructure of science and technology.

There is reasonable consensus and a sound rational argument for the federal government to be concerned with the health of the national technical enterprise. Such consensus and rationale disappear quickly when federal support for R&D turns to specific missions, even to specific industries, which call for considerations of economic and market factors, and can disrupt the competitive actions within the industry in both domestic and international markets.

* Federal support for civilian-sector applied research is more likely to be effective when coupled with some indirect federal action, such as procurement.

The fundamental weakness in federal support for civilian-sector R&D is the lack of coupling to the manufacture and use of products or processes derived from technical change. Thus, government agencies are at a disadvantage in assigning priorities, setting specifications, and achieving successful transfer of the results. But when there is an overriding national objective that justifies government procurement of various civilian goods and technologies, the government is in a much better position to understand the technical and market parameters; and government R&D support coupled to this procurement can help spur technical change in the civilian sector while serving its own procurement goals.

* Civilian-sector R&D derives benefits from the stronger technical infrastructure and increased reservoir of science and technology provided by public-sector R&D.

Programs conducted by and for the civilian-sector -- our very considerable body of industrial research -- have access to a higher level of science and technology because of the continuing public-sector technical efforts, e.g., by NASA and Department of Defense. Thus, the technical efforts of the civilian sector itself is more effective for those personnel engaged in its research. The level of knowledge for new graduates, particularly those with graduate degrees who have experienced some research operations, is higher in part because of public-sector R&D.

* Federal support of civilian-sector R&D is more effective when there is reasonable involvement of the industry sector concerned.

This is the fundamental rule for coupling government efforts to the system which must integrate and convert technical activities to useful products, processes, and services. The nature of the programs and of the national objectives may justify government involvement, but industry inputs and activities can be a critical factor in planning, conducting, and transferring R&D. When national objectives appear to preclude such government-industry cooperation, the results will surely be less effective and more expensive.

* Successful federal support of mission-oriented civilian-sector R&D must be compatible with existing technical community.

Success implies transfer to use. Construction of a final prototype or pilot plant resulting from a major program, the ability to manufacture something economically -- these things require a particular level of technical capabilities in fields of materials, controls, chemical engineering, and so on. Federal efforts in a public-sector mission can and do finance the parallel programs required to implement R&D. Federal efforts in a civilian-sector mission must rely upon the existence of the appropriate technical skills in industry. The appropriate balance of knowledge and capabilities is a critical factor in any program, and one that is normally not within the control of the federal government in civilian-sector missions.

B. Support for Infrastructure of Science and Technology.

The most pervasive, acceptable and effective form of federal support for civilian-sector R&D is strengthening of the technical infrastructure. This means:

1. Support of mechanisms to provide trained technical graduates.

2. Increasing the reservoir of science and technology.

These activities are conducted typically in non-industrial institutions. Our comments thus are focussed primarily on universities and government laboratories. However, new forms of mission-oriented research institutes or other mechanisms have been considered for pursuit of broad generic technologies, e.g., welding, and these could be established as independent institutions, possibly with ties to universities.

Any federal involvement in civilian-sector R&D represents a separation between the funding source and the user. Support of basic research or generic technology creates a further separation between the general nature of R&D being conducted and the specific needs of product and process requirements within industry. Thus, particular issues arise concerning priorities for research programs and transfer of results.

There is general consensus within industry and, indeed, within the entire technical community that a proper government role exists for supporting infrastructure R&D. There is no consensus on mechanisms; on criteria for establishing priorities; on relations among funding agency, R&D producer, and user; on provisions for proprietary positions; on transfer mechanisms. Public consensus about the role may mask serious differences about approaches and effectiveness.

These issues raise questions and potential conflicts for the university. Our data base for this subject arises partly from the interviews within this study, and even more from a parallel study on university-industry research cooperation by the NYU Center for Science and Technology Policy. Anecdotal and quantitative data are contained in a report currently being submitted to the National Science Foundation under Contract No. NSB-80-24731, titled University-Industry Cooperation: The Examination of Existing Mechanisms.

The emphasis of universities on basic research, and the fact that the university is a third-party in any government-industry interaction, define the strengths and weaknesses of the university as a component in civilian-sector R&D. Let us consider this three-way system in more detail.

There is a clear consensus among universities, industry, and the federal government that university research is strongest and most compatible with the functions and obligations of a university when it is devoted to basic research. There have been no substantial considerations from within the university or industrial communities to move the university systems toward applied research. But there has been some evidence of misunderstanding within the federal government and of concern within the university community about the various expressions of interest in "supporting" industrial needs, in providing new ideas to stimulate "innovation," that have arisen in recent years.

There have indeed been several attempts within the history of the National Science Foundation, for example, to establish programs that would support applied research, most of which would have been conducted at universities. To the extent that such activities were addressed to some need in our national technical effort, they are within the legitimate mission of the Foundation. However, to the extent that such activities are perceived to be a response to the needs and desires of industry, such efforts are a misunderstanding of the preferred relationships between university and industry.

When they are articulated at all, expressions of industry preferences for changes in traditional university procedures fall loosely into two categories. One is a desire to strengthen basic engineering sciences in addition to the basic physical sciences. The other is a wish to strengthen interactions in general so that university basic research can be planned with at least a knowledge of those areas of science in which industry can indentify a need for more effort.

Thus, any actions of the federal government to support civilian-sector R&D through funding of basic research at universities would be in line with the expectations and understanding of industry. Having stated this, it is also clear that there are strong opinions within industry and universities as to how such actions can be most effective. These separate communities are not in complete agreement on the most desirable conditions, but the area of disagreement may not be as wide as the caricatures of university and industry approaches might suggest, and there are indications that such disagreements are lessening.

There are clear examples of this within the university structure. Many of these issues that appear disturbing to the basic physical sciences have long been resolved in those departments and schools which have a tradition of partnership with associated industries.

Thus, agricultural research and medical research have had important linkages with the relevant components of the food and pharmaceutical industries. Engineering departments in general have close research ties with the chemical, mechanical, and electrical industries. There appears to be an accepted equilibrium among research support from industry, graduate training, and freedom of research. Probably the simplest comment of this section would be that the universities themselves would profit by studying the mechanisms used by the professional schools in developing relationships with the users of their research and their education.

At the start of this section, we suggested that both strength and weakness are inherent in these two university characteristics: (1) that the emphasis is on basic research and (2) that the university is a third party in any program of federal support of civilian-sector R&D. These statements should be clarified.

The strengths are obvious. It is valuable to have an institution which can pursue new frontiers of knowledge with some continuity without an imperative for near-term payoffs. The limitations inherent in strongly mission-oriented institutions could inhibit the pursuit of new directions and militate against longer-term commitments and risk-taking. The third-party independence of universities is some insurance of objectivity, thus minimizing considerations of past commitments or biases related to traditional procedures that could influence the choice of technical options.

But characteristics that provide strength in the independent pursuit of new knowledge can be sources of weakness for the integration of technical progress into social and economic systems, i.e., the civilian-sector. There are finite resources available for any activity, including basic research. Thus choices are being made constantly on allocations to fields of research, to departments, to specific projects, and so on. These allocations are made at many decision levels: within a university, within a federal agency, within a private corporation, indeed within the mind of an individual researcher.

Stated simply, not all areas of basic research are equally likely to be of value to all technical needs of the civilian sector. Any advance in basic science or engineering can lead to further advances and future benefits, unexpected. And serendipity is a valid fact of basic research, given that unplanned application of results can follow any research effort. Nevertheless, the current need to develop alternate secure economic sources of raw materials, including pursuit of ocean mining, is more likely to be aided by basic research in process metallurgy and geophysics than by basic research in the atomic structure of alloys, to take an example from the materials field.

How do we achieve greater compatibility between the distribution of basic research within universities and the needs of the civilian sector for basic science and engineering? Should we try to influence this distribution in order to derive the optimum value for society from such activities?

The answer, presumably, is that there is no reason to select either the extreme of pure randomness for university research or of a completely detailed allocation system by fields and projects. There can obviously be a realistic balance between (1) undirected basic research, supported principally on the criteria of good research, growth of a field, and quality of the researcher; and (2) directed basic research, supported on these criteria plus the relevance of subject matter to needs of society, in practice, to the objectives of the sponsoring organization.

To achieve such a balance requires, in addition to many intellectual capacities, a healthy communication system that brings university researchers in reasonable contact with the system for integration of technical change into the civilian-sector. It is here that the third-party nature of universities, a fundamental requirement for freedom of inquiry and independent action, can be a barrier to the necessary linkages that should exist between university research and those institutions which can extract benefits from it. The challenge lies in overcoming the inherent disadvantages of non-involvement while preserving the inherent virtues of independence and objectivity.

This is of particular importance to the specific subject of this study. That is, when the federal government funds university research as a means of strengthening civilian-sector R&D, there is a particular obligation to develop appropriate linkages among all three sectors. Great interest is evident today in university-industry research cooperation. While much of this interest derives from possible misunderstandings as to who needs whom and for what, there is a solid legitimate function that such interaction fulfills. At the very least, it is an important factor in achieving the allocation of national efforts in basic research that will accomodate both the traditional independence of university research and the needs of the civilian sector as represented by industry. Details on all of these issues are provided in the study referred to for the National Science Foundation.

There is a continuing and, we believe, healthy period of experimentation and self-examination now underway within universities and within the external institutions concerned with university research, namely, federal agencies and industrial research. The objective is to help universities to provide the optimum contribution to the technical progress of society. It calls for interdisciplinary research when all the incentives of the university system are in opposition. It calls for close relations with industry even though the traditional university researcher considers "relevance" to be irrelevant, if not improper. It calls for federal funds to shore up the financial structure of universities when there is equal concern for the independence of university actions.

There is no fundamental incompatibility among the legitimate scientific and technical interests and objectives of the three sectors. There is a genuine concern on the part of both government and industry executives to achieve improved linkages with university research without damage to its true strength for individual research, for exploratory efforts in new directions, for independent action. The many initiatives being considered and tried will broaden the exposure and thinking of all groups. That alone will be a major step to increase the effectiveness of university research with regard to the civilian-sector.

The broad agreement on "infrastructure R&D" follows a general belief that the government's role is most effective and legitimate when it does indeed strengthen the infrastructure of science and technology. It is most ineffective and questionable the more it touches on design, on conversion to use, and on issues involving economics and markets. It is not so much the simple distinction between basic research and product development. Rather, it is more an issue of providing a stronger base for advances by many interests without favoring any one.

The more basic -- the less the research is related to specific end items -- the more willingness there is for priorities to be set by the research scientist and the funding agency. The more applied -- the more the research relates to an identifiable need for understanding and data -- the greater the desire for participation by the user.

Thus, the theme that government should support basic or generic programs is tempered by the caution that the precise subject matter should suggest the best mechanisms and conditions of such support. That, in part, is the lesson of COGENT.

C. Role of Indirect Federal Actions.

This study was focused upon direct federal support of civilian-sector R&D. Yet, as the accompanying industry studies have reminded us, federal influence on technical change is exerted through a wide range of indirect instruments of federal policy.

The particular observation we wish to emphasize here is the effectiveness of federal R&D programs when coupled with indirect actions of the federal government. The classic instrument is procurement, and the great success stories lie in the public sector. These provide lessons to support observations from the industry studies and from individuals interviewed that can be instructive for the civilian-sector.

It is clear from our experiences from World War II to the present that federal R&D programs in areas where the government is the final customer have been very effective in technical achievement, transfer, and use. The two principal factors for this success are:

1. Minimum uncertainty regarding market acceptance and financial resources for conversion and use.

2. Sufficient familiarity with the user needs to guide technical specifications and set priority for technical program.

These are guidelines for any successful R&D program. They are often lacking in federal R&D programs intended to support the civilian sector. Nevertheless, they have been present in some areas with positive results.

The examples most commonly and properly referred to are in aircraft and electronics. Federal support for R&D coupled with procurement for government use led to considerable technical change in those industries. The success in achieving useful technical change derived classically from government familiarity based upon government needs, plus the economic underpinning provided by procurement. The nature of these industries, which were able to commercialize advances at the leading edge of their technologies, permitted effective transfer.

The example of synthetic fuels points up the possible conflict between effectiveness and desirability. Federal R&D programs in synthetic fuels can be made more effective when procurement of a plant or of output is involved. Whether in fact the synthetic fuel program is a desirable national objective must be addressed as a separate issue. Certainly, procurement should not be used simply to increase effectiveness of federal support for R&D, thought it might well have that result.

A program not analyzed in this study, but relevant, is the former Experimental Technology Incentive Program (ETIP) within the Department of Commerce. Experiments conducted within ETIP demonstrated clearly that federal procurement, operating in part to create demand, in part to establish specifications, could indeed lead to desired technical change. It is a powerful tool when used constructively.

The interesting point that emerges, therefore, is that federal support for R&D when coupled with procurement can be effective in generating technical change in areas where the government is not the principal user.

It is reasonable to expect a similar conclusions for the combined use of other indirect mechanisms as, for example, regulations. Again, we should not confuse effectiveness with desirability. Nevertheless, a current major study being completed by the Office of Technology Assessment on the influence of regulations on innovation suggests that such actions provide both the climate and familiarity to improve effectiveness of federal R&D programs.

D. Significance of Public-Sector R&D to the Civilian-Sector.

This study is focused on actions of the federal government in supporting R&D intended for the civilian-sector. We have not been concerned with indirect mechanisms or with indirect technology transfer.

Nevertheless, our ultimate underlying interest is with the forces that produce technical change in the civilian sector, and with their relative effectiveness. The companion set of industry studies contained many examples of the role of indirect federal mechanisms such as procurement, regulation, and taxes. For the sake of completeness in discussing important factors -- but with no pretense of depth -- we would like to present some perspectives concerning the role of federal support of R&D not intended for the civilian sector. These emerge both from the industry studies and from the discussions with government and industry executives throughout this study.

The principal areas of public sector R&D are in defense, space and, at least in an earlier period, atomic energy. Defense and space R&D constitute more than 60 percent of all federal R&D expenditures in 1980.[2] Hence, there has been a continuing concern from many quarters about "spin-off" or "fall-out" or "technology transfer." These concerns go back at least to the end of World War II, when the sheer magnitude of federal R&D programs stimulated interest in deriving further benefits beyond that of national security.

This has led to two extreme schools of thought. One is that the hundreds of billions of federal R&D dollars spent since 1950 in public sector areas constitute a gold mine of technical leads, of products and processes, of patents that could feed into the civilian-sector if only we would process the ore. The other is that R&D conducted for public-sector objectives without regard to civilian-sector specifications is inherently of little immediate value for transfer, requiring more effort to convert and adapt for civilian purposes than to develop the desired technologies from scratch. A corollary to this second school is that the fraction of national R&D efforts devoted to public-sector programs constitutes a drag on the availability of technical options to improve productivity, economic growth, and international competitiveness.

The common-sense observations derived from careful review of different industry sectors is that the answer is a bit of both. If anything, somewhat more value should be attributed to the role of public-sector R&D than has been accepted as "common knowledge" in recent years. To expand on this, let us consider the several categories in which we can view potential impact on the civilian-sector from these activities.

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2. Shapley, _et_. _al_., _Op_. _Cit_., p. 17.

The following is somewhat oversimplified in order to provide a brief overview of this broad subject. We can consider the impact of public-sector R&D on the civilian-sector in these three areas:

1. Technical developments that support certain specific industry sectors. The role of NASA and DOD has been critical, and of great but not easily calculable economic value, to electronics, aircraft, and communications.

2. Wide-spread strengthening of the scientific and engineering infrastructure of the nation. This includes (a) advances in knowledge throughout the technical spectrum of basic sciences, electronics materials, structures, energy conversion, and so on; (b) expansion of university capabilities in both faculty and facilities; (c) advances in the tools of science and technology -- instrumentation, standards, automation, computers.

3. Specific output of new materials, products, instrumentation or processes that can "spin-off" into civilian-sector applications.

It is this third item that has received primary attention as a potential source of considerable value for industry adaptation to civilian-sector use, and which has been consistently disappointing to those who considered such conversion to be easy or cheap. Conversely, the first and second items, while appreciated and taken for granted, have probably been somewhat underestimated with regard to their pervasive and long-term economic values.

These issues take on more critical importance in the current situation in which direct federal support for civilian-sector R&D is being de-emphasized while R&D related to defense is being increased. There will surely be potential economic benefits from the increased reservoir of technical advances and technical personnel plus the specific contributions to technical change from programs such as

VHSIC (Very High Speed Integrated Circuits). There will be some changes in overall industrial productivity, some new product innovation, and some effects on the balance of international trade. Will changes be more positive because of these public-sector programs than would have occurred if a greater fraction of such federal support had been earmarked for the civilian-sector?

No easy quantitative answer is possible. It may well be that the value of the public-sector programs for the private sector, while largely indirect, has been underestimated, at least within the United States. This point should be studied in more depth. Personal observations of the authors are that European analysts tend to assign great credit to our defense and space programs for much of the overall industrial progress of the United States in recent years. Presumably the primary source of these benefits derives from one or more of the following:

1. There have been significant technical advances in micro-electronics, computers, telecommunications (including satellites) and so on, which have provided the opportunity for the development of new businesses and the growth of some existing businesses.

2. Industrial research is made more productive and can advance further in developing new products and processes by drawing upon the added technical advances in materials and scientific procedures as, for example, computer sciences, analytical and measurement techniques, and physical processes such as lasers and plasma.

3. The productivity of industrial operations are improved by the advances in computers and data handling, controls and automation, sophisticated inspection and production equipment, inventory control systems, and so on.

4. Technical graduates entering industrial research or operations come with a broader competence in electronics, advanced materials, measurement and control techniques as a result of the stronger and more advanced university base.

These are advantages for the civilian-sector. Nevertheless, there have been disadvantages even in the general support for R&D. A principal concern in the period just prior to 1970 was the emphasis on university research on technical problems related to the challenges of defense and space -- such as materials science -- with an apparent lessening of interest in the more mundane needs of the civilian-sector -- such as process metallurgy. An immediate consequence was a perceived parallel decline in the interest of technical graduates in industrial careers. This perception is undoubtedly complicated by the general period of unrest at universities in the 1960s, and does not follow simply from federal funding of university research.

The point is that federal support of public sector R&D does affect the civilian-sector in complex ways -- mostly positive, certainly not negligible, and not easily susceptible to cost-benefit analysis. Can any measures be taken to improve the effectiveness of this effect? Earlier in this section, we suggested that "spin-off" receives recurring attention and is very largely disappointing. One fundamental basis for such disappointment is that "technology transfer" normally takes place after the R&D is completed to the specification of the public-sector need. This is hardly unexpected, since the public sector provided the funds.

Suggestions have been made within NASA and DOD that some consideration to private-sector needs be given much earlier in the R&D process, while program plans are still being formulated. Thus, for example, an alloy development which could have commercial implications might proceed with joint participation by one or more interested companies. The private firms would pay incremental costs for the added

R&D required to meet civilian-sector needs, and the final output would be more easily convertible to economic use.

There are difficulties in such procedures given the urgency of defense needs, the mixing of public and private funds, and the necessary incentives for both parties. But the concept of early dialogue and involvement in R&D planning does contain possibility for smoothing some of the mis-match between public-sector and private-sector needs, hence increasing the probability of deriving added value.

We should also point out that the opportunities for strengthening civilian-sector R&D through the indirect mechanism of public-sector R&D are very dependent on the technical field and on the nature of the work performed. Since the bulk of R&D expenditures for both defense and space are devoted to engineering activities and hardware, only a modest portion of these funds can be credited with raising the general reservoir of scientific and engineering knowledge. For example, four percent of DOD and 11 percent of NASA expenditures are considered to be in the area of basic research.[3]

Nevertheless, public-sector R&D has provided a reservoir of professionals across a broad spectrum of sophisticated technical disciplines. And a very large amount of money in the past 30 years from these sources has increased our level of scientific and engineering knowledge.

This has diminished the number of technical people and funds that could have been devoted to direct support of civilian-sector R&D. But those engaged in industrial research and in related activities funded by government were able to draw upon a stronger technical base. Since we are dealing

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3. Shapley, et. al., Op. Cit., pp. 22 and 48.

here with questions of creativity, of technical ingenuity, and of the complex process by which we create and use technical change, there is no quantitative estimate possible to compare our industrial and economic position today with what might have been. Would more people devoted to civilian-sector R&D drawing upon a lower technical base have put us in a better position than we are in today?

The issue is not calculable, but some judgments are clear. Civilian-sector R&D has undoubtedly been strengthened by public-sector R&D. The U.S. is in a strong technical position today, a leader in many fields, and with a growing capacity to generate new technology. Once the commitments are made to public-sector objectives, any civilian-sector benefits are a bonus. And the bonus in R&D has been considerable.

E. Importance of Existing Technical Community.

An important factor in the initiation and conduct of any research program is the existence of technical personnel in the area of interest. This is the essential element in basic research, and it is a critical factor in the effectiveness of applied research and development.

The effectiveness of R&D intended for the civilian sector is often dependent on the existence of a broad range of available technologies and related technical specialists throughout the scientific and engineering spectrum. The conduct and integration of a large-scale R&D activity into a complex industrial system normally requires contributions from a range of disciplines and is often dependent on parallel technical advances in relevant fields. The history of technology contains many examples of developments that were "timely" or "premature." This is due very largely to the existence or non-existence of the required technical system to render the new development compatible with the potential applications.

In comparing the cases of agriculture and housing, for example, we saw that the much-remarked-upon level of technical progress in the former case and its equally noticeable absence in the latter are partly traceable to the well-developed community of agriculture scientists as compared to the relative lack of any network of technical specialists in the building trades. Furthermore, we saw in many cases -- including aircraft and computers -- that the development of one technology involves a dovetailing with advancing technology in related support areas. As the Russians discovered, getting to the moon is as much a problem of computer technology as of rocket technology.

The point is that there is a critical difference between public-sector areas, e.g., national security, and civilian-sector areas. A federal program in which the government is the final customer can attempt to identify and support all the necessary technologies required for the complete development and application of the technical program in question. Two of the clearest examples of such efforts in recent years are the Manhattan Project during World War II and the space program of the 1960s.

In contrast, federal support of R&D intended for the civilian sector is dependent for its effective transfer and integration into economic use on either (1) the ready availability of appropriate technologies or (2) activities in the private sector that can eventually develop such technologies in parallel. While the federal government can provide for a particular technical advance, the economic application may call for simultaneous advances in many related materials or methods of manufacture.

It is the function of the market to coordinate much of the required activity. But the judgments and initiatives required to account for all these factors in civilian-sector R&D also call for the existence of a technical community possessing the range of technologies required. This community can be developed, to some extent and with great effort, by government funds in public-sector programs. It must be an existing and participating force for effective civilian-sector activities.

The considerations discussed above refer to the limitations of government programs and agencies in providing and controlling the mix of technologies required for technical advances in the civilian sector. In principle, there is every reason to assume that any such deficiencies would be recognized and taken into account prior to initiation of a given program.

There is another aspect, however, which calls for more detailed interactions between federal R&D programs and the industry affected. This is the question of technologies and skills required for the economic design and manufacture of products and processes that would normally follow a successful R&D program.

Effective industrial research requires reasonable coupling between the R&D process and the manufacturing process. Knowledge of available materials that are suitable for the processes called for, and an understanding of the nature of those manufacturing techniques suitable for application to the technical advances under consideration, can be critical to the complete innovation process.

Thus, the existence of an appropriate technical community in the materials, components, and processes of manufacturing required for the conversion of R&D is essential to the effectiveness of any overall program in the civilian sector. And familiarity with these factors, difficult enough within an industrial research organization, becomes far more elusive when we consider federal R&D efforts.

For all these reasons, the existence of an appropriate technical community is critical, and the detailed knowledge about that community can come only from reasonable participation of industry in the program. This was an important lesson in the development of titanium for aircraft, involving close partnership between government and industry. It is critical in current advances in microelectronics, where production is inseparable from R&D. But the principle is applicable well beyond these areas of high technology, and is a major consideration for improved effectiveness of federal support for civilian-sector R&D.

F. Cooperative Industrial Research.

When the federal government supports R&D, it is acting collectively for the general public. Yet we have seen that the federal government acting in the civilian sector can be inefficient without the involvement of private corporations responsible for the ultimate investment, manufacturing, and distribution.

There are indications that some forms of collective action by the private sector can substitute for government programs and simultaneously provide a mechanism for involving the judgments and cooperation of the industrial research community. Where this approach can be pursued effectively, it is indeed one to be encouraged.

There is increased activity by a number of industries to set up a formal organization which will collect funds and use them to support both infrastructure R&D for that industry and, in some sectors, specific developments that can advance the non-competitive interests of the industry. The two largest are probably the Electric Power Research Institute (EPRI) and the Gas Research Institute. EPRI was initiated in 1973, and has current annual R&D expenditures of $217 million. GRI was initiated in 1976, with current annual R&D expenditures of $83.7 million.[4] Two new efforts now being organized are in the chemical and the semiconductor industries. Both are planning annual expenditures in the $20 to $30 million range.

In general, research done by trade associations has been more substantive and productive in Europe than in the U.S.[5] Basic research funded by trade associations in the U.S., performed usually at universities, has been very modest. Thus, the changes represented by the recent trade association programs are along two lines:

1. These are sizable commitments by a number of industries to produce technical advances basic to those industries.
2. They are deliberate efforts, particularly by the chemical and electronic industries, to influence the direction of public funds and of university efforts by indicating those areas of basic science and basic engineering of relevance to industry and by strengthening particular programs.

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4. Figures are from the 1980 annual reports of EPRI and GRI.
5. For a balanced view of trade association research in Britain, see P.S. Johnson, Co-operative Research in Industry, New York: John Wiley, 1973.

All of these efforts are being pursued with strict attention to the guidelines for acceptable cooperative programs among companies that have evolved from anti-trust considerations by the Justice Department. Thus, these collective research efforts emphasize basic infrastructure R&D or, at most, developments that can be available on non-exclusive license to all comers.

This presents somewhat of a paradox in recent concerns about the international competitive position of the United States. Japanese technology-based products, particularly in consumer electronics but increasingly in a broad range of advanced products and systems, appear to demonstrate a capacity for rapid and economic adaptation of new scientific advances. Federal initiatives in stimulating university-industry or government-industry cooperation, or even cooperative industry efforts compatible with Justice Department guidelines, have been motivated in part by the desire to strengthen our technical position vis-a-vis foreign competitors, particularly Japan. Yet these efforts, emphasizing primarily basic research, publishable results, open licenses -- all in accord with accepted anti-trust practices -- are of almost as much benefit to a foreign competitor as to the U.S. In fact, if one really believes that Japan is superior to the U.S. in the ability to adapt and exploit scientific advances, then such efforts could diminish our competitive position.

We do not accept that extreme interpretation. But there is a point, raised by several of those interviewed in this study, that our international competition might be improved by some forms of collective industrial actions that would call for some re-appraisal of anti-trust guidelines. These would lean towards more emphasis on specific developments, possible restrictions on licensing, and so on. The intent would be to expedite technical advances while spreading the cost and risk, but collective action could presumably be justified only when it would not lessen our criteria for domestic competition.

To our knowledge, no good study has been made of the economic benefits and costs that would be incurred if there were more joint ventures in applied R&D, nor is the current legal stance completely clear. We make no legal recommendations. The topic here, we think, calls for serious study.

There may also be a gray area creating opportunities for collective industry actions in applied research and developments, without calling for a business arrangement for exploitation by the partners. This might help our international competitive position or simply substitute effective private initiatives to replace less effective federal actions. In either case, there is good reason to call for serious consideration by appropriate federal agencies as to whether laws and regulations intended for domestic objectives can be modified to accomplish new international objectives without affecting adversely the original intent.

G. Concluding Remarks.

We would like to close with what perhaps should have been the opening. Our concern has been with the "effectiveness" of federal R&D programs intended for the civilian sector. By this, we refer to the effective allocations of technical resources measured by conversion to use within the economy. And this economy is one in which goods and services are produced and distributed by the private sector.

We have not considered any social or economic theory other than this. That is to say, we did not address such questions as to whether a particular federal action or inaction has an effect on the relative distribution of small companies versus large companies within an industry; on competition within an industry; on the distribution of the future work-force in terms of skills and education; and so on. Other objectives are implied by such questions, and there are inevitably inherent conflicts in almost any set of national objectives.

Effective science and technology policy means many things. In the broadest sense, however, it means two: first, that we are providing for the health of our national technical enterprise; second, that we are taking those actions and adopting those policies which make the optimum use of our total technical resources in achieving a broad range of national objectives.

This study focused on one aspect of science and technology policy, namely, actions of the federal government to support R&D intended to help the civilian sector. We were not concerned with support of public-sector R&D, with indirect actions of the federal government, or with the industrial research activities funded by industry.

Thus, on the one hand, we did not seek or obtain a complete picture of technical change in the civilian sector. We were, however, made acutely conscious of the major factors that influence this change and the interactions they have with each other. We have attempted to bring these perspectives to bear upon the one factor that was our objective: direct R&D support by the federal government.

Hence, a simple overriding guideline for such direct federal actions is that they must be taken with full knowledge of the other factors influencing technical change, and with the conscious effort to develop mechanisms that link the factors together. Our discussion of general principles and specific underlying themes presented in this final chapter spell out many of the implications of this statement.

And when should the federal government become involved in supporting civilian-sector R&D? The answer is essentially a political one. We have chosen to take "effectiveness" as a basis for the answer, and to measure this in terms of our economic system wherein the private sector is responsible for the ultimate manufacture and sale of economic goods derived from technical change. Any other measure for economic or social reasons would pay some price in cost or time or optimum allocation of technical resources.

We have not provided a set of recommended direct actions, but rather a set of recommended indirect guidelines. This is not a solution to the question of how and when the federal government should provide for the most effective support of civilian-sector R&D. It is, however, a suggested road map towards that solution.

BIBLIOGRAPHY

Anonymous, "Making U.S. Technology More Competitive," Business Week, January 15, 1972, p. 44.

Arrow, Kenneth J. and Robert Lind, "Uncertainty and the Evaluation of Public Investments," American Economic Review, June, 1970.

Barfield, Claude E., "High-Technology Package Focuses on Domestic Needs, U.S. Trade Balance," National Journal, October 23, 1971, p. 2114.

Barfield, Claude E., "High-Technology Research Program May Include Tax and Anti-trust Proposals," National Journal, October 31, 1971, p. 2156.

Bazell, Robert J., "NSF: Is Applied Research at the Take-off Point?" Science, vol. 172, June 25, 1971, p. 1315.

Boffey, Phillip M., "Technology and World Trade: Is there Cause for Alarm?" Science, vol. 172, April 2, 1971, p. 37.

Boffey, Phillip M., "Unemployment: What Nixon Is/Isn't Doing to Help Jobless Scientists," Science, vol. 171, March 12, 1971, p. 985.

Brodsky, Neal H., Harold Kaufman, and John Tooker, University/Industry Cooperation, New York: Center For Science and Technology Policy, 1980.

Brooks, Harvey, "What's Happening to the U.S. Lead in Technology?" Harvard Business Review, vol. 50, no. 3, May-June, 1972, p. 110.

Cooperative Automotive Research Program, "Technical Framework: Research Area Working Groups," in Congressional Record, Senate, November 18, 1980, pp. S12813-S12834.

Eads, George, "U.S. Government Support for Civilian Technology: Economic Theory Versus Political Practice," Research Policy, vol. 3, 1974, p. 2.

Fusfeld, Herbert I., Perspectives on U.S. Industrial Innovation, New York: Center for Science and Technology Policy, 1981. (With an annotated bibliography by Theodore W. Schlie.)

Gillette, Robert, "Technological Initiatives: NBS Funds In Holding Pattern," Science, vol. 179, January 12, 1973, p. 163.

Greenberg, D.S., "Civilian Technology: Concern Over Pace of Growth Inspires Program for Research and Development Effort," Science, vol. 139, February 5, 1963, p. 576.

Greenberg, D.S., "Civilian Technology: Opposition in Congress and Industry Leads to Major Realignment of Program," Science, vol. 143, February 14, 1964, p. 660.

Greenberg, D.S., "Civilian Technology: Program to Boost Industrial Research Heavily Slashed in House," Science, vol. 140, June 28, 1963, p. 1380.

Hamilton, Andrew, "State Technical Services Act: Congress Swings the Axe," Science, vol. 166, December 26, 1968, p. 1606.

Hammond, Allen L., "Federal R&D: Domestic Problems Get New Efforts But Little Money," Science, vol. 171, February 19, 1971, p. 657.

Holsendolph, Ernest, "Senate Passes AT&T Decontrol," The New York Times, October 8, 1981, p. A-1.

Industrial Research Institute Research Corporation, "Cooperative Technology Program: Evaluation of Nine Candidate Areas for Industry Participation and Support," Revised Version, December 16, 1979.

Large, Arlen J., "A 'Monument' Industry Innovation Law Crumbles," The Wall Street Journal, July 15, 1981, p. 34.

Nelson, Bryce, "Technological Innovation: Panel Stresses Role of Small Firms," Science, vol. 155, March 10, 1967, p. 1229.

Nelson, Richard R., Merton Peck and Edward Kalachek, Technology, Economic Growth, and Public Policy, Washington, D.C.: The Brookings Institution, 1967.

Nelson, Richard R. and Sidney Winter, "In Search of a Useful Theory of Innovation," Research Policy, vol. 6, 1977, p. 36.

Pavitt, K. and W. Walker, "Government Policies Toward Industrial Innovation: A Review," Research Policy, vol. 5, no. 1, January, 1976.

Peters, Lois and others, University-Industry Cooperation: The Examination of Existing Mechanisms, New York: Center for Science and Technology Policy, October, 1981.

Rosenberg, Nathan, Perspectives on Technology, Cambridge: Cambridge University Press, 1976.

Shapley, Deborah, "Magruder in White House: SST Man Plans New Technology Take-off," Science, vol. 174, October 22, 1971, p. 386.

Shapley, Deborah, "Technology and the Trade Crisis: Salvation Through a New Policy," Science, vol. 179, March 2, 1973, p. 881.

Shapley, Deborah, "Technology Incentives: NSF Gropes for Relevance," Science, vol. 179, March 16, 1973, p. 1105.

Shapley, Deborah, "Technology Initiatives: Hints on the Magruder Effort," Science, vol. 175, January 21, 1972, p. 279.

Shapley, Willis H., Albert H. Teich and Gail J. Breslow, Research and Development: AAAS Report VI, Washington, D.C.: American Association for the Advancement of Science, 1981.

Smith, Philip M., Testimony before the Subcommittee on Science, Technology, and Space, Committee on Commerce, Science and Transportation, U.S. Senate, mimeograph, April 30, 1980.

Stans, Maurice, "Science, Technology, and the Economy," Statement before the House Subcommittee on Science, Research, and Development," July 27, 1971, reprinted in NBS Technical News Bulletin, November, 1971, p. 270.

U.S. Department of Commerce, "Cooperative Generic Technology Program Procedures," Federal Register, vol. 45, no. 159, August 14, 1980, pp. 54028-54031.

U.S. Department of Commerce, Office of Cooperative Technology, "Cooperative Technology Program: Key to Industrial Innovation," Revised Draft, January 24, 1980.

U.S. Department of Energy, Office of Conservation and Solar Applications, The DOE Industrial Conservation Program: A Partnership in Saving Energy, Washington, D.C., no date.

U.S. Department of Energy, Office of Conservation and Solar Applications, "Industrial Energy Conservation Program Threshold Analysis," Washington, D.C., mimeo, no date.

U.S. General Accounting Office, Major Science and Technology Issues, PAD-81-35, Washington, D.C., January, 1981.

U.S. Office of Management and Budget, Toward a Uniform Procurement System, Task Group 3 Project Report, July 25, 1980.

U.S. Senate, "National Technology Innovation Act of 1979," 96th Congress, Second Session, Report No. 96-781, May 15, 1980.

Wade, Nicholas, "Nixon's New Economic Policy: Hints of a Resurgence for R&D," Science, vol., 173, August 27, 1981, p. 794.

Walsh, John, "Myron Tribus, Top Science Official, Resigns," Science, vol. 170, December 4, 1970, p. 1065.

Zerkel, Fred H., "White House Shapes Strategic Approach to R&D," Chemical and Engineering News, March 20, 1972, p. 24.

APPENDIX: INDIVIDUALS CONSULTED BY INTERVIEW OR AT MEETINGS.

Leonard A. Ault, Acting Chief, Dissemination & Analysis Branch, National Aeronautics and Space Administration.

Thomas Baron, President, Shell Development Company.

Arden L. Bement, Jr. - Acting Deputy Undersecretary of Defense for Research and Engineering (Research and Advanced Technology) Department of Defense (now Vice President, Technical Resources, Science and Technology, TRW, Inc.)

Frederick Betz - Industry/University Cooperative Research, Industrial Science and Technological Innovation Division, National Science Foundation.

Frank E. Block - Deputy Director for Minerals Research, U.S. Bureau of Mines.

Paul C. Bogiages - Project Development Manager, Corporate Research and Development, General Electric Company.

Myles Boylan, Policy Analyst, Policy Research Analysis Division, National Science Foundation.

Alfred E. Brown - Director, Scientific Affairs, Celanese Corporation.

Arthur Bueche - Senior Vice President, Corporate Technology, The General Electric Company.

John D. Caplan, Executive Director, Research Laboratories, General Motors Corporation.

Will D. Carpenter, Director of Environmental Operations, Monsanto Agricultural Products Company.

J. Hoyt Chaloud, Manager, Research and Development Coordination - International, Procter & Gamble.

Paul F. Chenea, Vice President, Research Laboratories, General Motors Corporation.

F. A. Cleveland - Vice President of Engineering, Lockheed Corporation.

Donald W. Collier - Senior Vice President, Corporate Strategy, Borg-Warner Corporation.

George de Stevens - Research Professor of Chemistry, College of Liberal Arts, Drew University. (Formerly Executive Vice President, Pharmaceuticals Div., Ciba-Geigy Corporation.)

Fred H. Dietrich - Associate Administrator, Office of Management and Budget, Office of Federal Procurement Policy.

Lewis W. Eckert - Assistant Director of Research Armstrong Cork Company.

Lansing Felker - Assistant Director, Office of Cooperative Technology, Department of Commerce.

George Gamota - Assistant for Research, Research and Advanced Technology, Office of Under Secretary of Defense for Research and Engineering.

Felix J. Germino - Vice President, Research and Development, Human Foods, The Quaker Oats Company.

Thomas Glennan - The Rand Corporation.

Ralph Gomory - Vice President and Director of Research, International Business Machines Corporation.

N. Bruce Hannay - Vice President, Research and Patents, Bell Laboratories.

Walter L. Hardy - Director, Research and Development, The Richardson Company.

Douglas Harvey - Acting Deputy Assistant Secretary, Department of Energy.

Gregory T. Haugan - Director, Research and Special Programs Administration, Transportation Programs Bureau, Department of Transportation.

George F. Hausmann - Associate Director of Research for Program Development, United Technologies Corporation.

Thomas Henrie - Chief Scientist, U.S. Bureau of Mines.

Henry Hertzfeld -- Economist, National Aeronautics and Space Administration.

John Holmfeld - Science Consultant, Subcommittee on Science, Research and Technology, Committee on Science and Technology U.S. House of Representatives.

Ralph J. Johnson - Vice President, National Association of Home Builders Research Foundation.

Charles B. Kenahan - Deputy Director - Minerals Research, U.S. Bureau of Mines.

Andrew Kenopensky - Automotive Coordinator, International Association of Machinsts and Aerospace Workers.

Paul D. Klimstra - Vice President, Pre-clinical Research and Development, C. D. Searle & Co.

Lawrence Kushner - Senior Staff Associate, National Bureau of Standards

Donald N. Langenberg - Deputy Director, The National Science Foundation

M. A. Manganelli - Technical and Budget Advisor, Mobil Research and Development Corporation.

L. G. Maury - Vice President, Development Hercules Incorporated.

Stephen A. Merrill - Subcommittee on Science, Technology, and Space, Committee on Commerce, Science and Transportation.

Richard Meserve - Senior Policy Analyst, Office of Science and Technology Policy, Executive Office of the President.

Robert Newton - Senior Staff Associate, Director of Grants and Contracts, National Science Foundation.

Warren D. Niederhauser - Director of Pioneering Research, Rohm and Haas Company.

Alfred H. Nissan - Vice President (Retired), Westvaco Corporation.

Nat C. Robertson - Director and Scientific Advisor, Marion Laboratories

Joel Snow - Senior Science Associate, Office of Energy Research, U.S. Department of Energy.

Donald E. Stitzenberg - Director of Corporate Planning, Merck & Co., Inc.

Edward S. Tabb - Manager, Industrial Utilization Research, Gas Research Institute.

Gregory Tassey - Planning Office, National Bureau of Standards.

John E. Tessieri - Vice President, Research and Technical Development, Texaco, Inc.

Louis Tornatzky - Head, Innovation Processes, Policy Research Analysis Division, National Science Foundation.

William Rubin - Director, Research Division, Sperry Rand Corporation.

Jack Sanderson - Assistant Director, Engineering Directorate, National Science Foundation.

Joseph Sherman - Director, Division of Energy, Building Technology and Standards Research, Department of Housing and Urban Development.

Hedvah L. Shuchman - The Futures Group.

A. E. Smick - Professional Staff Member, Subcommittee on Science, Technology and Space, Committee on Commerce, Science and Transportation, U. S. Senate.

Guenther O. Wilhelm - Manager of Coordination and Planning, Exxon Research and Engineering Company.

Richard Woldin - Science Fellow, Subcommittee on Energy Research and Development, Committee on Energy and Natural Resources, Congress of the United States.

John H. Young - Office of Technology Assessment, Congress of the United States.

END

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FEB 24 1982