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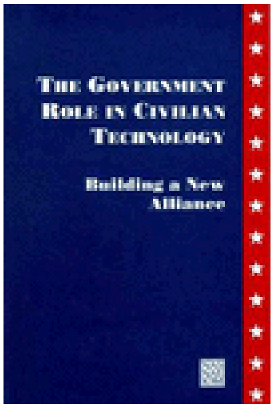

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THE NATIONAL ACADEMIES
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THE GOVERNMENT ROLE IN CIVILIAN TECHNOLOGY

Building a New Alliance

Panel on the Government Role in Civilian Technology

Committee on Science, Engineering, and Public Policy

National Academy of Sciences
National Academy of Engineering
Institute of Medicine

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This report has been reviewed by a group other than the panel according to procedures approved by COSEPUP and a Report Review Committee comprised of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

The role of the United States government in research and technology development is now an important part of the national debate. Increases in real incomes for U.S. citizens rest not only on a stable and benign macroeconomic environment, but also on investment in R&D, technology, physical capital and infrastructure, and on education of the work force, among other factors. In some of these areas, and overwhelmingly in the key steps of commercialization and responding to the market, the private sector does and should predominate. Government investment in some of them, however, contributes directly to technological innovation, the entry into the market of new products and processes and, therefore, to growth in real incomes.

Dramatic changes have taken place in the global economy over the past several decades that make federal investment in technology more important than at any time since World War II. Some of these changes include: a decline in East-West military tensions; the growing challenges from foreign competitors in commercial markets; and an increase in the importance of international trade to the U.S. economy. Even as we face a world economy newly shaped by these and other developments, the evidence and data suggest that the innovative capacity, and much of the U.S. manufacturing base remain strong. Many U.S. firms are highly competitive in global markets based on a view across a wide range of industry sectors. It is misleading, as some have done, to generalize about the U.S. competitive position from a few firms or industries. The U.S. economy (though it is growing more slowly than that of Japan or Western Europe), and in particular the nation's ability to generate new technology, is not in decline.

Sound public policy and a productive response to strengthening our competitiveness will require action by both government and the private sector in many areas. These include restoring literacy and numeracy through improvements in primary and secondary education, investing in training of the work force, and modifying corporate management practices, among others. We must also find ways of lowering the cost of capital, if we can agree on and adopt a course to do so.

Strengthening the U.S. economy will also require significant changes in U.S. technology policy. The U.S. needs a policy that moves beyond a focus limited to support for basic research and for the development of technology to meet national security needs. A new federal role should include facilitating (not directing) civil technology development in pre-commercial areas and the adoption of new technologies by U.S firms.

Long accepted and acted on in federal policy for basic research, there is also a clear government role in support of pre-commercial, generic technology. This involves areas where the social value of investment exceeds easily identifiable economic value (which does not include the effects of externalities such as environmental preservation and reduced dependence on oil imports from unstable regions). The economic benefits to society from this form of research and development exceed those appropriable by the firm that carries it out. This is the rationale for government action in pre-commercial technology that goes beyond the sphere of basic research. The difficult question is "how should this new federal role be executed?" There are several ways.

This report focuses on programs that, in our judgment, have the greatest possibility to build on the nation's strength in research and innovation, and at the same time contribute to U.S. economic performance. The Defense Advanced Research Projects Agency (DARPA) can play a part in improving the nation's civil technology base by moving again to fulfill its role in dual-use technology. This is especially the case for those areas related to computers and information handling and processing, which increasingly drive technology with military applications. In addition to DARPA, this report also reviews federal laboratories and their capacity to contribute to private sector technology development.

Cooperative R&D projects and government financial support for joint ventures can also (though they will not automatically) contribute to private sector technical advance. This may be especially true when cooperation is facilitated by government in conjunction with a stable macroeconomic environment and policies to promote private savings and investment. Other factors that play a part in the success of joint government-industry R&D,

and important lessons of past federal efforts in the U.S. to facilitate civil technology development, are outlined in our report.

Current federal programs in a few mission agencies can be built upon to work with the private sector in pre-commercial R&D. A more fundamental change in technology policy is necessary, however, which goes beyond reorganizing and extending programs now in operation. The report provides options for the creation of a new mechanism to facilitate pre-commercial R&D and fulfill this objective. Finally, the report includes guidelines that should be followed in any government-industry program in this area. No matter which options are exercised by Congress and the Administration to shape a new technology policy, these guidelines should be carefully considered.

The report does not examine macroeconomic policies that affect private sector technology efforts. It covers only briefly some federal programs in technology referenced in our Congressional charge. For example, although technical information services to U.S. companies provided by the federal government can aid U.S. industrial competitiveness over the long-term, other forms of federal-industry cooperative arrangements reviewed in this report can benefit civilian technology development in a more fundamental and substantial manner.

The Congress, in the Omnibus Trade and Competitiveness Act of 1988, requested a study of the National Academies of Sciences and Engineering, and the Institute of Medicine upon which this report is based. The Academies were asked to form an expert group from industry, labor, and those with past government experience, to review programs and policies of the federal government to support private sector research and technology. Much of the success of this project is directly related to the fine work of the individuals represented from those sectors on the panel.

The panel and staff have been careful to base the information in this report on data, evidence, and previous analyses whenever possible. In some instances, however, material presented here represents the collective judgment and expertise of the group, as we note in the text.

The National Academies assembled an outstanding staff to conduct this project. We wish to express our appreciation and recognize the contribution of this professional and highly qualified group. They played a key role in ensuring the successful completion of the study. John Wilson, the Study Director, managed the project at the Academy, facilitated consensus within the group, and drafted substantial sections of the report. Edward Moser provided staff support on the project in 1991. Alfreda McElwaine served as administrative assistant during 1991. Nancy Crowell provided critical professional support during the later stages of the project in preparing the manuscript for final publication.

On behalf of the panel, I would also like to extend our thanks to all those who contributed to this project from government, industry, and universities. In particular, I want to express our appreciation to those who conducted briefings for the panel. Many representatives of federal agencies, including especially staff of the National Institute of Standards and Technology (NIST) provided assistance to the Academies and the panel throughout the project. I want to extend our special thanks to Dr. Robert Chapman, the technical liaison to the study from NIST, for his dedicated assistance and professionalism throughout the project.

HAROLD BROWN
Chairman

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THE GOVERNMENT ROLE IN CIVILIAN TECHNOLOGY

Building a New Alliance

OVERVIEW

The development and adoption of advanced technologies are critical factors in economic growth. Productivity and economic growth are also affected in a fundamental way by public and private savings rates, the educational skills and quality of the work force, and investment in infrastructure, among other factors. Manufacturing quality, as well as the sound management of U.S. firms, affects our ability to increase productivity and long-term standards of living. Without progress toward correcting deficiencies in these areas, the recommendations in this report will be less effective in meeting the national challenges ahead.

The government's role in civilian technology must also be revised to meet the challenges of the post-Cold War era. The United States can construct a technology strategy by leveraging national strengths in science and innovation. This can be done without detailed government direction of industrial performance or interference with the market forces that drive economic advance.

GUIDELINES FOR FEDERAL INVOLVEMENT

To be effective, certain guidelines must be followed in executing this mission. Government-industry R&D ventures with public sector support should (1) include cost-sharing provisions; (2) involve—indeed flow from—project initiation and design by private firms; (3) be insulated as much as possible from political concerns; (4) include a diversified set of R&D objectives; (5) undergo rigorous project evaluation and review; and (6) be open to foreign firms characterized by substantial contribution to U.S. Gross Domestic Product (GDP).

Strengthening Government Technology Programs

The first step in building a new alliance between government and industry in civilian technology is action to strengthen federal programs that facilitate private sector research and development, and the transfer or adoption of technology. Specifically,

- the Defense Advanced Research Projects Agency's role in dual-use technology development—especially in the area of information technology—should be reaffirmed;
- a small number of the 700 federal laboratories should be selected to work with private firms in an effort to enhance technology transfer;
- the scope of selected mission agency R&D programs should be enlarged to include pre-commercial projects;
- funding for the Small Business Innovation Research program should be increased;
- the Advanced Technology Program has had a promising start—although past budgets were insufficient to have a significant impact on technology commercialization—and should be evaluated, by an independent group, to determine the desirable size of the program; and
- a new Industrial Extension Service should be created at the Department of Commerce to speed technology adoption by U.S. Industry.

Federal Responsibilities Beyond Current Programs

A new technology strategy for the post-Cold War era must include more than revisions in current federal programs. The government should act to correct the failure of private markets to support pre-commercial R&D. It should create incentives for private investment at this important point, where firms cannot appropriate (capture) the economic benefits of investment. Just as the government acts to prevent underinvestment in basic research through federal funding, policymakers must recognize and should alleviate market failure somewhat downstream in pre-commercial R&D, as well.

Promoting Investment in Pre-Commercial R&D

The most appropriate way to promote any substantial federal investment in pre-commercial R&D is through creation of a Civilian Technology

Corporation (CTC). The goal of a CTC would be to increase the rate at which products and processes are commercialized in the United States. This objective can be met by stimulating investment in the pre-commercial stage of technology development with high social rates of return, where firms cannot appropriate sufficient benefits of R&D work. Higher levels of investment at this stage of the innovation process will, over the long-term, translate into stronger U.S. performance in technology commercialization.

The CTC would be a quasi-governmental organization, funded through a one-time, $5 billion congressional appropriation. A board of directors, appointed by the president and subject to Senate confirmation, would manage the corporation. The performance and operation of the CTC would undergo an independent, thorough review after the fourth and tenth years of operation.

THE RATIONALE FOR CHANGE

By many measures, the United States remains strong in technology and continues to exhibit considerable industrial strength. We are the most productive nation in the world. Manufacturing output is increasing at a rapid rate; U.S. exports of manufactured goods are growing. As measured by indicators such as patents awarded and the balance of trade in high-technology goods and services, among others, the innovative capacity of the United States remains unsurpassed.

Although the nation's technological performance, relative to its past, is strong, this does not mean that U.S. policy should continue unaltered. The technological competence of our trading partners continues to increase. We need a better balance in technology policy, one that includes support not only for basic research but also for pre-commercial R&D. Moreover, the ability of U.S. companies to adopt new technologies, an important part of economic growth, is weak. As in pre-commercial R&D, market failure is evident in this stage of the technology development process. The federal government should act to address this deficiency.

The most important reason for a new technology policy, one that builds on our comparative strength in research and innovation, centers on productivity. Long-term productivity growth rates remain lower for this country than for our foreign competitors. The United States needs to improve its performance in all areas that promote productivity growth. Investment in civilian technology to achieve higher rates of technology commercialization and adoption is one part of the solution. We should move quickly to achieve this goal.

1

The Environment For Technology Development

This report focuses on an important part of the competitive dynamic of any industrialized nation: the role and responsibility of the federal government, in cooperation with private sector firms, to facilitate technological progress. It is important, in any assessment of this subject, to begin with a brief overview of U.S. economic performance and the context in which government-industry cooperation in technology takes place.

Economic advance, of which technological innovation is a key component, is characterized by the ability of a nation to create and produce goods and services that meet global market needs, while at the same time supporting growth in real domestic incomes. The forces that drive economic growth and increases in domestic living standards depend in turn on many interrelated scientific, technological, managerial, social, and economic factors. These include continued improvements in productivity in both the manufacturing and the service sectors, and a stable macroeconomic environment. A skilled, motivated, and mobile work force and management; a strong research, development, and technology base; and progress in incremental advances in product and process technologies are also important. The ability of the public and private sectors to invest in R&D and physical capital, including infrastructure, is a fundamental part of economic advance, as well.[1]

There are indications that compared with previous postwar periods, the performance of the U.S. economy may have declined during the past 20 years. The fundamental problem facing the United States is the slow rate of productivity growth. Growth in productivity is important for a number of reasons. Most importantly, it determines, in large part, national standards of living. A country that enjoys strong real growth in productivity over time can expect a corresponding increase in wages and income for its citizens. Nations with increasing productivity also have the capacity to support investment in programs that affect the quality of life for society as a whole. At the individual firm level, productivity growth rates determine, in part, the ability to compete effectively in global markets.

The rate of growth in labor productivity in the private, nonfarm business sector in the United States, which averaged 3.3 percent annually during 1948–1965, declined to roughly 1.2 percent after 1970. The slowdown in productivity growth has important implications for growth in domestic income. Had labor productivity growth maintained its pre-1965 average annual rate, by 1985 the total U.S. output would have been 45 percent higher than it actually was. Since 1973, labor productivity growth rates have dropped significantly, as has growth in real hourly earnings. Hourly compensation, which includes fringe benefits, has grown at only 0.8 percent annually since then.

There has been strong growth in per capita personal income, however, which includes not only wages and fringe benefits, but also dividends, rents, and transfers to compensation. Much of the divergence between the growth in per capita income and stagnant compensation growth rates appears to be due to rapid expansion of labor participation, growth in income from nonlabor sources, and a decline in real hourly wage rates of nonsupervisory (production) workers.[2]

Lower rates of growth in productivity and compensation also mean that the generation of workers entering the work force during the past 10 to 15 years—particularly production workers in positions that are usually associated with lower levels of skill, training, and education—faces the prospect of lifetime earnings and living standards lower than those of its parents. This is a risk as long as real compensation growth remains stagnant over time for these workers.

This report examines an important part of U.S. productivity growth and long-term standards of living: the development, commercialization, and adoption of new technologies. Based on our analysis of this subject, the panel has concluded that U.S. policy, as it relates to civilian technologies, requires change. The structure of postwar U.S. science and technology policy was in many important ways a response to the Cold War. With the passing of the Cold War and other developments in the international economic, political, and technological environments, modifications in U.S. policy toward civilian technology development are justified.

Modifications in U.S. technology policy, however, will be insufficient by themselves to reverse the trends in U.S. productivity and income growth evident over the past two decades. Without complementary revisions in macroeconomic policy (particularly increasing public and private savings rates), strengthening of the public educational system, improvements in the performance of U.S. managers, and higher standards of manufacturing quality, design, and engineering, this report's recommendations for change in civilian technology policy will be less effective and possibly futile.

This chapter summarizes trends in recent U.S. economic performance and assesses the relationship between these trends and U.S. technological performance. A brief description of the technology creation, commercialization, and adoption process follow this discussion. The analysis presented in this chapter and subsequent material in Chapters 2 and 3 will show that there is a legitimate federal role in pre-commercial R&D and technology development. The United States can construct a technology policy that facilitates investment in these areas. It can strengthen current federal programs and implement new ones that leverage U.S. strengths in science and technological innovation.

PRODUCTIVITY GROWTH

It is important to note that an objective assessment of national economic and technological performance will show areas of both strength and weakness. Some analyses and public policy statements issued the past decade on U.S. performance have focused exclusively either on dramatic deficiencies in one sector of the U.S. economy or, in contrast, on areas of significant strength. In many cases, conclusions on the performance of the U.S. economy, in comparison to the nation's competitors, have been drawn from a few select examples and have failed to acknowledge the wide areas of broad strength in the nation's performance. The following discussion outlines, in summary fashion, areas of both concern and strength in the United States.

As noted, the single greatest weakness in recent U.S. economic performance is the disappointing rate of growth in labor productivity since the early 1970s. There are economic forces that serve to reinforce productivity growth, as well as those that amplify declines in growth rates. In addition to contributing to earnings and household incomes, higher productivity growth rates can provide for higher levels of private sector investment in science and technology-related assets. Strong productivity performance also supports higher levels of public investment in infrastructure and human capital (education, training, and skill enhancement).

Recent declines in labor productivity growth are not confined to the United States. Productivity performance in most of the member countries of the Organization for Economic Cooperation and Development has been poor since the mid-1970s, relative to growth rates from 1950 to 1974.[3] Moreover, although U.S. productivity growth has slowed in recent years,

TABLE 1-1 Real Gross Domestic Product Per Capita Based on Purchasing-Power-Parity Exchange Rates

Country	1950	1960	1970	1980	1985	1987	1988	1989	1990
United States	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Canada	69.5	72.0	78.1	92.1	93.2	94.1	94.5	94.2	93.9
Japan	16.1	28.8	55.8	66.1	71.2	71.9	73.1	74.9	80.7
Korea	NA	9.5	12.9	20.9	26.4	31.1	33.2	34.4	38.1
France	44.4	54.4	65.8	73.1	70.7	69.8	69.5	70.1	73.7
Germany	36.0	61.1	67.9	74.3	73.0	72.5	72.3	72.8	74.5
Italy	31.7	44.9	57.3	67.1	65.9	66.2	66.6	67.3	69.0
United Kingdom	60.4	66.5	64.9	66.2	66.4	68.4	68.7	68.6	69.8

NOTE: NA = Not available.

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Office of Productivity and Technology, July 1991.

the level of U.S. labor productivity remains the highest in the world. The United States, as shown in Table 1-1, continues to outperform other countries in real gross domestic product (GDP) per capita. The measured rates of productivity growth for U.S. manufacturing, in particular, have improved significantly compared to the very low growth rates of the 1970s and early 1980s. (Some portion of this improvement, however, may be the result of changes in the measurement of manufacturing output in such high-technology industries as computers, as well as changes in the organization of manufacturing establishments.)

Although manufacturing productivity growth in the United States has improved in recent years, current data may overstate this improvement somewhat. Likewise, poor productivity growth in the nonmanufacturing (service) sector of the U.S. economy may reflect the lack of up-to-date data and the difficulty of measuring productivity growth. These difficulties have been compounded by underinvestment by federal agencies in data collection. Measurement of productivity in the service sector has clearly not kept pace with changes in the economy in recent decades.[4]

As shown in Table 1-2, average annual labor productivity growth in the U.S. nonfarm business sector slowed from a rate of 2.2 percent during 1960

TABLE 1-2 Productivity Growth for Selected OECD Countries (percentage changes at annual rate)

	1960-1973	1973-1979	1979-1990
Total factor productivity[a]			
United States	1.6	-0.4	0.3
Japan	5.9	1.4	2.0
Germany	2.7	1.8	0.8
United Kingdom	2.3	0.6	1.6
OECD Europe	3.3	1.4	1.3
OECD	2.8	0.5	0.9
Labor productivity[b]			
United States	2.2	0.0	0.7
Japan	8.6	2.9	3.0
Germany	4.6	3.1	1.6
United Kingdom	3.6	1.6	2.1
OECD Europe	5.0	2.7	2.0
OECD	4.1	1.4	1.5

[a] Total factor productivity is equal to a weighted average of the growth in labor and capital productivity. The sample-period averages for capital and labor shares are used as weights.

[b] Output per employed person.

SOURCE: Adapted from Organization for Economic Cooperation and Development, OECD Economic Outlook #50, 1991, Table 48.

to 1973, to no growth from 1973 to 1979. It rose an average of only 0.7 percent per year from 1979 to 1990. Labor productivity in Japan, Germany, and other nations followed a similar, even steeper pattern of declining rates of growth. In Japan, annual productivity growth fell from an average of 8.6 percent during 1960 to 1973 to a rate of 2.9 percent in 1973 to 1979, for example. Surprisingly, despite considerable research, economists have yet to develop a widely accepted explanation for the post-1973 global decline in productivity growth. Most scholars nonetheless agree that declines in rates and changes in the nature of capital formation, changes in the composition of the labor force, the energy price increases of the 1970s, and lower rates of growth of R&D investment contributed to this decline. Each of these factors is examined, in brief, in the following pages.

Capital Investment

International comparisons of productivity growth rates show a strong correlation between higher growth of capital input per worker (or higher levels of investment) and higher productivity growth rates. One reason for this relationship is the fact that technological advances are often embodied in new physical capital (plant and equipment). In order to reap the benefits of robotics technologies, for example, a firm must invest in new production equipment. One study of postwar economic growth in five industrialized nations found that the benefits of technological progress are "capital-augmenting."[5] In other words, it is possible to show that technical progress is biased toward capital investment and that capital and technical progress are complementary. The benefits of technical progress are larger with larger capital stocks (total level of plant and equipment in an economy).

Other scholars have estimated that "capital-labor" substitution, or replacing labor (hours worked) with capital equipment, contributed 19 percent of U.S. productivity growth from 1947 to 1985 and 13 percent of growth from 1979 to 1985.[6] Another recent survey of the contribution of capital investment to productivity growth found that increased capital quality contributed 28 percent of U.S. productivity growth from 1947 to 1985 in the United States, with a 30 percent contribution to overall growth in 1979 to 1985.[7]

Declines in the rate of capital formation in the United States, therefore, may have contributed to the recent productivity slowdown. An examination of the 1970s, however, does not show lower rates of gross investment in physical capital in the United States relative to previous periods. Gross investment was sustained at historic levels during the 1970s and continues to grow today. The rate of growth in capital input, however, has not kept pace with expansion of the labor force, especially during the 1970s.[8] Thus, productive capital available per worker has declined. Moreover, the com position of the capital investment of the 1980s shifted slightly to favor greater investment in real estate and less in physical plant and equipment.[9]

Demographic Shifts

Changes in the demographics of the U.S. work force may also have contributed to lower rates of productivity growth after 1973. The U.S. work force grew rapidly during the 1970s, as the baby-boom generation entered the workplace. The ability of the U.S. economy to absorb this large expansion in workers without sharp and sustained increases in unemployment rates is itself a remarkable achievement. Many Western European economies have fared less well in absorbing their baby-boom generations and women into their domestic work forces, which has contributed to the relatively high and sustained unemployment rates in Western European economies since the mid-1970s.

In the United States, rapid expansion of the work force during the 1970s and 1980s made it far more difficult to maintain historic levels of labor productivity growth. In addition, the changing composition of the work force associated with the entry of baby boomers and the increase in labor force participation rates of women meant an expansion in less experienced workers as a share of the total work force. As one estimate of changes in the work force suggested, the U.S. shift of labor resources to lower-productivity workers between 1970 and 1983 decreased average productivity growth (based on 1979 employment shares) by 0.2 percent.[10] Other widely cited studies have also found that changing demographics in the United States, especially since the late 1960s, have contributed to lower productivity.[11] Since the U.S. labor force now is growing more slowly and is forecast to grow roughly one-half as rapidly through much of the 1990s as it did during the 1980s, this source of downward pressure on productivity growth rates should be reduced, at least for the intermediate term.

Rising Energy Prices

Disruptions in world oil markets also played a role in the productivity slowdown. Dramatic increases in energy prices during the 1970s may have accelerated the rate of obsolescence of existing plants and equipment, thus increasing the levels of capital investment required to maintain previous levels of productivity growth. World energy prices quadrupled in 1974 after the Organization of Petroleum Exporting Countries set benchmark prices for crude oil, and they rose again in 1979 and 1980. These sharp rises in energy prices caused serious disruptions in the economy, contributed to inflationary pressures, and quickly made much of the existing stock of plant and capital equipment, as well as other energy-inefficient investments, ob solete. Increases in energy prices, therefore, contributed to lower rates of growth in labor productivity, although higher prices did direct investment to energy-saving structures and equipment, with great improvements in energy efficiency.

Slowdown in Research and Development Spending

Spending on research and development also contributes to productivity growth. A number of studies have found a link between industrially funded R&D investment and productivity growth at both the individual firm and the industry levels. Most of these studies also suggest that industrially financed R&D does not affect productivity for at least three to six years. This delayed effect, which is even longer for basic research expenditures, reflects the time needed to commercialize and adopt innovations based on R&D investment. Therefore, the slowdown in industrial R&D expenditure growth in the U.S. economy during the early 1970s may well have had an impact on labor productivity growth rates into the 1980s. The resumption of growth in industrial R&D expenditures after 1975 would have similarly delayed effects, as will the recent (1988–1991) declines in growth in industrial R&D expenditures.

The reasons for the change in the growth rates in industrially funded R&D expenditures in the United States during the 1970s and 1980s are not well understood. Nonetheless, there is little doubt that U.S. industry for some years has been investing less of its own funds in R&D (measured as a share of gross national product) than has Japanese or German industry. Since 1970, domestic U.S. industrially funded R&D has accounted for a smaller share of U.S. gross national product (GNP) than have Japanese or German industrially funded R&D expenditures (measured as a share of Japanese and German GNPs, respectively). When comparing nondefense R&D expenditures as a percentage of GNP from all sources (industry and government), the United States has also invested less than other nations. In 1971, for example, the United States, Japan, and Germany spent 1.7, 1.9, and 2.0 percent of GNP on nondefense R&D, respectively. The U.S. investment in R&D has now fallen well behind that of its industrial competitors. In 1987, the U.S. share was still 1.7 percent, whereas Japan and Germany had shares of 2.8 and 2.6 percent, respectively.[12] As noted below, U.S. federal R&D expenditures are largely devoted to defense-related work. This fact, combined with the sizable portion of U.S. national R&D investment that is funded from public sources (which substantially exceeds the proportion in Japan and Germany), means that U.S. nondefense R&D expenditures (from public and private sources) account for a smaller share of GNP than do Japanese and German nondefense R&D.

TECHNOLOGY CREATION, COMMERCIALIZATION, ADOPTION AND TRANSFER

The economic performance of the United States during the last decade combines areas of strength and weakness. The United States does, however, retain global dominance in scientific research and "innovation" (defined below), as revealed in Nobel Prizes and citations of papers published by U.S. scholars, among other indicators. The innovative capacity of the United States, relative to its past performance, we believe, has not declined.

The panel has concluded, however, that the nation requires a better-balanced technology policy that includes support not only for basic research but also for pre-commercial R&D and technology adoption. The United States can leverage its strengths in science and invention to increase the rate of technology commercialization in the economy. The environment for technology development has changed. This has contributed, in part, to changes in the circumstances through which the economic returns to research and technology are captured. To illuminate this assertion and lay the groundwork for an analysis of changes in the environment for technology development, we now turn to a discussion of the processes through which technologies are created and yield economic returns.

Technology Creation

The creation and realization of economic benefits associated with new technology involve a number of phases that interact with one another and frequently extend over a lengthy period of time. The initial phase, the creation of new technology, is often referred to as "invention," and typically involves fundamental scientific and engineering research that demonstrates a basic concept or proves the feasibility of a specific solution to a problem. This first phase of the technology development process often involves basic research efforts. In the United States, a significant portion of this "upstream" research in both industry and universities has been supported by the government. (During 1985 to 1988, roughly two-thirds of all basic research performed in the United States was supported by federal funds.) In many cases, results from the invention phase lead to the publication of scientific papers or applications for patents. The results of this phase, however, are rarely translated into commercial sales or large profits.[13]

Commercialization

Invention is followed by "innovation," or commercialization. This phase involves the translation of a scientific or technological advance into a commercial product. The focus of the vast majority of industrial R&D expendi tures is not on research (the "R" of R&D) but on development, an activity that includes the technical components of commercialization of new scientific or technological advances. It also may involve the improvement of existing products or processes through the application of such advances. In many instances, innovation requires the combination of a number of technological or scientific advances in an improved version of an older product. In other cases, it requires a very large investment of resources in the "scaling up" of production facilities to manufacture commercial volumes or to "debug" devices that have been proved to operate in the laboratory.

Those involved in translating a new scientific or technological advance into a commercial product often are not the same individuals responsible for the underlying invention or discovery. Moreover, the time lag between invention and innovation may be quite long, and much of the "science" that underpins contemporary technological innovation may in fact be based on research performed decades earlier. Nevertheless, the invention and innovation phases of the creation of a new technology are not strictly sequential, but often interact with one another. Problems encountered in translating new science into new products often feed back into the scientific research process. The development of radioastronomy, for example, originated in efforts to reduce background noise in long-distance telephone communications. Almost always, manufacturing processes, as well as consumer preference and product development requirements, are key elements of the development process.

Successful innovation results in a new process or product that may yield large profits to the firm or individual responsible for the innovation. This requires investment in a wide range of "complementary" activities that extend well beyond narrowly defined scientific inquiry or engineering work. Improvements in production processes, for example, are often required to manufacture a new product at the lowest possible cost. The commercialization of a new product may also require significant investments in distribution and marketing networks. Moreover, the magnitude and importance of these investments often mean that individuals or firms that first introduce a new process or product may not capture much of the profits from it. Rivals are often able to quickly imitate or duplicate technological advances.

The economic returns of new technology assume two forms: (1) profits to the individual innovator (or shareholders of a corporation), along with higher wages and compensation for workers; and (2) benefits to the economy channeled through the adoption of new products and processes by other firms. The latter also includes benefits to consumers through a wider range of product choices that better satisfy human needs. The commercial introduction of a new product or the application of new technologies to improve an established product (e.g., automobiles) often produces large sales at a high price, yielding significant profits to the innovating firm or entrepre neur responsible for successful commercialization or improvement. These profits in turn are distributed to shareholders. In many instances they are reflected as well in above-average wages and salaries in the firm or industry responsible for successful innovations. Some portion of the U.S. economy's ability to pay high wages, relative to other nations during the postwar era, clearly reflects the successful commercialization of a stream of new products and processes by U.S. firms. If U.S. ability to successfully and rapidly commercialize new technologies declines, this source of competitive advantage and above-average wages and salaries will also decline.

Product innovations and improvements are extremely difficult to measure with conventional economic statistics. Their benefits often are not captured by conventional measures of productivity growth. Recent efforts by the Bureau of Economic Analysis of the Department of Commerce to adjust the data on the computer industry to reflect improvements in product quality (adjustments with important implications for measured productivity growth) have proved difficult and controversial. Such measurement problems are widespread in manufacturing. They are even more serious in the nonmanufacturing sector. This is true, in particular, because large numbers of new products that advanced information technologies have made possible go largely unmeasured in national income and productivity data. In both the manufacturing and the nonmanufacturing sectors, therefore, the productivity and output statistics often do not take into account the results of product innovation and improvement. Nevertheless, it is clear that the magnitude of the productivity slowdown is a problem for the United States.

Adoption

A second channel through which the economic benefits of new technologies are realized is their adoption by other firms within an economy. Firms that rapidly and effectively incorporate new process and product technologies into the production of goods and services often improve productivity and competitive advantage in ways that (at least in principle) are captured by conventional measures of labor productivity. The adoption of new technologies is a costly and often knowledge-intensive process. It involves investments in worker training, new capital equipment and plants, information collection, and product and process debugging. Indeed, many of the skills and capabilities necessary to be an effective innovator or creator of technology are also indispensable for the successful adoption of new technologies. The adoption of a computer-integrated work cell, or work station, for example, requires extensive customized software and the removal of special defects at the installation site. In addition, the technology undergoes modification and improvement during the adoption process, as the "hands-on" learning by users is fed back to developers and incorporated into redesigned versions of a machine or piece of software. As a result, other users of the technology may get an improved version of the original technology, which is a reason to delay commitment to a new technology. This is particularly true if the adoption of subsequent versions of a specific technology is expected to be relatively less costly and if waiting to adopt a technology does not put a firm at an immediate competitive disadvantage.

Other factors affecting the speed with which firms adopt new technologies include the costs of these new technologies. The costs in many cases depend on domestic interest rates and other factors affecting the cost of capital, the state of development of technical standards, and the level of worker skills. Because the adoption of most new technologies is the outcome of investment decisions, rates of gross domestic capital formation affect the rate at which the domestic capital stock is "turned over" and new equipment replaces older machinery. Economic factors affecting capital formation therefore may influence international differences in the rate of adoption of new technologies. Technical standards can reduce the information costs associated with evaluating and adopting new technologies (e.g., by reducing the requirements for extensive customization of a machine or system for a specific installation).

Finally, the skills of the production work force in manufacturing industries can influence the costs and the rate of adoption of new technologies. A work force that is functionally illiterate, for example, will require more expensive training than one that is well-endowed with basic skills. The influence of worker skills may be especially important for the adoption of computer-based manufacturing technologies (robotics, computer-integrated manufacturing, etc.), since these technologies often place greater demands on the cognitive and numerical abilities of production workers, as well as their ability to diagnose problems in the production process.

The costs of adoption may make it especially difficult for smaller and medium-sized firms to utilize new technologies. This is because many small and medium-sized firms have limited resources, lack access to external sources of capital, and do not benefit from the same economies of scale available to larger manufacturers that adopt new technologies.

The importance of technology adoption means, among other things, that the economic benefits from the innovative activities of high-technology industries are not confined to those industries, but potentially can be reaped by firms in so-called low-technology, less R&D-intensive industries. The international competitive performance of Japan, Sweden, and Germany is based in part on the ability of firms in "mature," less R&D-intensive industries (e.g., automobiles, machine tools, and textiles) to quickly and effectively incorporate new products and processes into their products.

Technology Transfer

The processes through which new technologies are created, commercialized, and adopted involve many different organizations and an extensive flow of information. Technology transfer within and among organizations underpins the translation of science into product, as well as the adoption of new products and processes. The process of technology transfer is complex and information-intensive. It is based to a large extent on the ability of individuals (and groups of individuals) involved in research to interact with those responsible for technology commercialization.

When these interactions do not take place, technology transfer is impeded. Geographic distance between firms is one reason technology transfer may be slow or nonexistent. Even within a single firm, large and separate divisions for research, manufacturing, and development can pose problems to effective technology transfer. Many of the barriers associated with transferring technology are unrelated to government agency policy, the level of funding for university research, or the lack of appropriate institutions and mechanisms to facilitate technology transfer.

The geographic and organizational barriers to technological transfer include divided missions, responsibilities, and rewards. Trying to correct these problems by creating new mechanisms or institutions that are both geographically and organizationally distinct from technology sources or targets is not likely to be effective. There are also psychological barriers to technology transfer. The "not-invented-here" syndrome is a significant obstacle to technology transfer within and among university, government, and industry laboratories. A lack of continuous communication between scientists and engineers, or between development and manufacturing engineers, can also inhibit technology transfer, for example.

An alternative view of technology transfer that has influenced recent federal government initiatives is the so-called linear model, which offers an incomplete and distorted view. The linear model of technology development suggests that ideas originate in pure research; are transferred to applied research; and from there, go on to advanced development and manufacturing. This model drives technology transfer programs in ways that do little to match the needs of industry. With the linear model, progress comes in great steps. In some instances, there are indeed breakthrough innovations that either create new industries or transform existing ones. Many of the technology transfer programs established by Congress and implemented by federal agencies have been modeled on this technology "push" framework. It assumes that federal laboratories funded by the government, for example, operate in this manner and are repositories for technologies that are of great value to industry. This is an incorrect assumption.[14] In semi conductor and computer manufacturing, for example, progress is made primarily through incremental improvements in a cyclical manner.[15] The driving force is speed in the manufacturing cycle. If a new idea is proposed at any time other than the beginning of a development cycle, it demands adjustments, testing, and problem solving that endanger time schedules, particularly with complicated manufacturing processes and products. Minor changes may cause reliability and manufacturing problems. Timing, therefore, is a critical part of the competitiveness equation. Teamwork is important to the development of a fine sense of timing in industrial research and development.

In general, successful technology transfer involves cooperative work among people whose interests and talents in development, research, and manufacturing are combined to meet the requirements of a specific goal. Linking research and development programs to the manufacturing and marketing segments of an organization is one way to ensure that technology transfer will occur rapidly enough to meet the demands of the market. The key to the success of these programs is shared technical visions and shared goals, including a mutually agreed-upon work plan and program timetable, division of labor among the joint program participants, and articulated product goals. Moreover, this type of technology transfer has to be ongoing; it cannot simply focus on one generation of technology. Projects must be organized so that, while development groups concentrate on the next product, a joint program is working on the technology for follow-on products, and research is targeted at the next generation out. Joint program coordination is the key to success.

To a great extent, technology transfer programs need to be tailored to individual cases. This point will be expanded in the next chapter of the report. There are key elements that carry through on nearly all successful transfer efforts. The participants all "get on the same wavelength." They know ahead of time, step-by-step, what they will be expected to accomplish and what their collaborators will be expected to accomplish. Finally, all parties have as clear an idea as possible of what product they want to bring to market.

Joint work, mutually agreed-upon goals, and a managed division of labor across organizational and disciplinary boundaries are the key to technology transfer. One of the reasons for the success of the national weapons laboratories is that the government has assumed the role of customer: setting specifications, taking delivery of the "product," and evaluating what was actually produced against the requirements.

The transfer process is especially difficult because so much of the knowledge necessary to advance the process of technology creation or adoption is not easily written down or codified in a blueprint or technical drawing.

This knowledge is not easily transferred among or within organizations without significant effort. In many instances, transferring a technology requires transferring the individuals in whom the knowledge resides. Moreover, the successful transfer of technological or scientific information often requires a sustained interaction between the individuals or organizations responsible for the research, on the one hand, and those responsible for its commercialization, on the other. The flow of information is by no means a one-way flow, and successful technology transfer often assumes the characteristics of a contact sport.

Among the processes of technology creation, commercialization, and adoption, the commercialization and adoption stages are the most fruitful sources of economic benefits. Realizing economic returns from scientific and engineering advances requires their incorporation into new or existing products or processes. As noted, U.S. performance in technology creation remains very strong, as indicated by a number of indices. In many sectors, U.S. firms and industries continue to exhibit significant strengths in technology commercialization, as well.[16] This does not mean, however, that we should not attempt to find methods of improving U.S. performance in technology commercialization, especially where private markets fail to provide for investment in pre-commercial R&D (defined in the box that follows). We believe that the historic focus of federal science and technology policy on basic research, as opposed to pre-commercial R&D or adoption, may contribute to an erosion in the ability of some important U.S. industries to commercialize and adopt new technology.[17] Concern over U.S. performance in adoption and commercialization has been expressed in a series of reports issued by other expert committees in recent years, some of which are referenced in this report (Chapter 2).

U.S. STRENGTHS AND WEAKNESSES

The United States continues to lead the world in basic research.[18] In comparison to other major industrialized nations, the United States has spent more as a percentage of GNP on basic research over the past several decades. Real growth in expenditures from 1986 to 1989, the most recent period for which data exist, was 3 percent per year. The United States invests approximately half of that funding in the world's most dynamic and productive system of university research. The United States will have to continue to develop programs to attract more individuals into careers in science and engineering, attempting to draw women and minorities into this system. There has already been some progress in this area. Women scientists and engineers, for example, now represent more than 13 percent of the total science and engineering work force, up from 11 percent in 1980. A

PRE-COMMERCIAL RESEARCH AND DEVELOPMENT

Research and development is a dynamic, complex process. It involves a wide range of activities that can include work usually associated with basic scientific research, as well as R&D in engineering design and manufacturing. The setting for R&D is equally diverse. Research is performed in university laboratories by a single, private investigator and also in corporate R&D facilities with several hundred researchers.

It is extremely difficult to measure precisely where basic, pre-commercial, and applied R&D efforts begin and one line of scientific inquiry is terminated. Moreover, research and development, as it relates to technological innovation and technical change, does not necessary follow a linear model or evolutionary, predetermined process. There are discreet examples of great breakthrough discoveries in science and engineering that have had significant impacts on technological innovation. Some of most notable technology leaps in the past 25 years include the development of the microprocessor, the discovery of optical fiber materials, and genetically engineered biotechnology products. Even these technological breakthroughs did not take place in isolation, however, but were developed by building on existing R&D and technical information bases and expertise. In sum, research and development, whether it unfolds under a series of incremental, evolutionary steps—sometimes with feedback from downstream, sometimes through continuous improvement—or under conditions in which significant technological and scientific breakthroughs occur, involves many actors and lines of inquiry that proceed with links and feedback between those engaged in the most basic search for new knowledge and those involved in activities just short of commercial product introduction.

The public policy debate over federal support for private research efforts has centered on questions about the nature of the research to be conducted with public funds. A central issue is whether a research project has successfully advanced so that the commercial potential and technical merit of the R&D are sufficiently clear to induce private funding of the effort. It is relatively easy to identify a project that is fundamentally basic in nature or one that involves work in new scientific areas in the search for knowledge. In these areas, there is a clear public need to provide funding through the federal government to support basic science and research. Private companies have little financial incentive to invest in R&D that will be available outside the company and therefore involves significant problems in appropriability for the firm. It is when scientific inquiry involves the promise of useful new knowledge that is generic in nature, with wide applications across economic activities, and there are insufficient private returns to investments in R&D that government must act.

Beyond basic research, there is an area of science and engineering work that falls short of product-or process-specific, applied R&D. This is R&D in *pre-commercial* areas, where lines of inquiry in basic scientific research have advanced beyond the search for new knowledge.* In pre-commercial R&D, technical knowledge and the scientific base for a potential advance in product or process technologies are at an early stage of development. It is in R&D work that significant barriers exist to private sector estimates of commercial market potential. Technical obstacles that represent serious, risky, and uncertain challenges to moving to the applied R&D or prototype development stage are present, as well. If these problems are successfully resolved, pre-commercial R&D may move into later-stage R&D, which is characterized by applied research, prototype development, and testing. This is where, in most instances, the economic potential of specific advances in products and processes becomes clear.

Pre-commercial R&D is also an area that can be identified by the existence of substantial "appropriability" problems. The ability of private firms to capture the economic benefits of investments in this type of work is limited. It is difficult, therefore, for private firms to appropriate or capture the knowledge, expertise, and insight that might result from R&D in these areas. The nature of pre-commercial R&D is characterized then by spillovers into the general knowledge base, where other firms can appropriate the economic "rents" or benefits of one firm's investments. In the absence of public support, therefore, there would be substantial underinvestment in potentially useful R&D work that might embody resulting advances in science and technology, with great social and economic benefit to the nation, as well as financial benefit to firms not investing. As noted in Chapter 2, R&D in which technical and market risks are high, costs associated with private investment are substantial, and appropriating the benefits of investment is difficult, contains a public good component that can appropriately merit government financial support.

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* For further detail on attempts to define pre-commercial, or pre-competitive, generic, or enabling R&D and technology, see: Office of Science and Technology Policy, *U.S. Technology Policy* (Washington, D.C.: Executive Office of the President, 1990) and U.S. Department of Commerce, *Advanced Technology Program: Proposal Preparation Guidelines, Proposal Solicitation-ATP 90-01* (Gaithersburg, Md.: Technology Administration, National Institute of Standards and Technology, 1990).

continuing U.S. strength is its ability to encourage and assimilate science and engineering talent from diverse population groups, especially in comparison to the poor record of other industrial economies.

The output of the basic research system in the United States also shows continued strengths in the nation's ability to support the creation of new technologies. The U.S. share of world scientific and technical literature, as reflected in data on the number of papers appearing in journals and other publications, has remained steady since 1945, averaging about 36 percent of total world output. Another indicator of national performance in technology creation is patents.[19] Patent data are particularly revealing in areas where patent protection is considered key to the ability to generate private profit. Although patenting in the United States declined during the 1970s, it recovered in the 1980s. Much of the fluctuation reflected changes in the levels of R&D spending by U.S. industry, as well as changes in funding for the U.S. Patent Office, which affect the time needed for processing applications and granting patents.

The United States continues to lead the world in the number of U.S. patents granted across a broad array of industries. A total of 54,762 patents were granted to inventors of U.S. origin in 1990, over 20,000 more than were granted to Japan, Germany, France, and the United Kingdom combined (33,875). Some nations, particularly Japan, have increased their share of U.S. patents granted over the past decade. The United States continues, however, to exhibit unsurpassed strength, evidenced in cycles during which patent grants have grown, slowed, and continued upward. Moreover, when data on patent applications are examined, as opposed to data on patents granted, the evidence (as shown in Figure 1-1) indicates that patent activity by U.S. residents in the United States did not slow down in any systematic fashion from 1953 to 1987.

The United States also remains a strong net exporter of technology. It leads the world in scientific output, as translated into patents, licenses, fees, and other transactions (intellectual property). As of 1989, the United States had a net of $1.3 billion in its technological balance of payments.[20] U.S. receipts (payments for intellectual property from foreign sources, excluding intracompany transfers) were roughly four times U.S. payments in 1989, essentially the same ratio as in 1979. In industries such as chemicals, commercial aircraft, and pharmaceuticals, U.S. firms have retained international competitive advantage by investing in the rapid incorporation of new technologies into products and maintaining state-of-the-art process technologies.

Moreover, the U.S. manufacturing base is not in decline. The United States is not deindustrializing, as has been suggested in the past by some analysts and public policy advocacy groups. For example, manufacturing output has accounted for a nearly constant share of GNP (constant 1982 dollars) since 1947.[21] Indeed, as a share of GNP output in 1988 (23 percent), it exceeded that of 1947 slightly (21 percent). The share of total GNP for most durable and nondurable goods sectors (manufacturing) over the period 1978 to 1988 remained stable (Table 1-3).

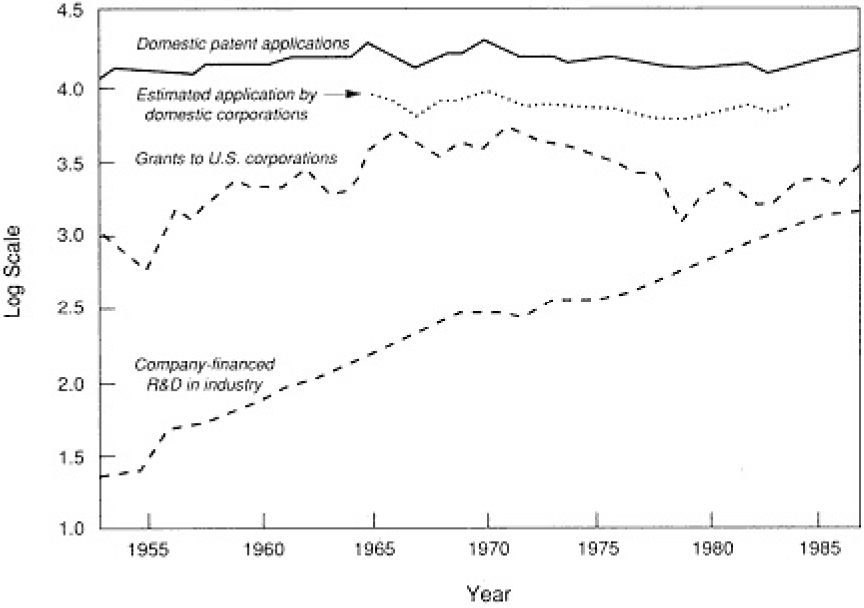

FIGURE 1-1
U.S. Domestic Patent Applications, Grants to U.S. Corporations, and Company-Financed R&D, 1953-87. Source: Griliches, Zvi. 1989. "Patents: Recent Trends and Puzzles," in *Brookings Papers on Economic Activity,* p. 293.

In addition, real output in manufacturing from 1978 to 1988 (from approximately peak to peak in the business cycle) grew in *all* categories of both durable and nondurable goods, except tobacco manufactures, leather and leather products, primary metals, and motor vehicles and equipment (Table 1-4). Table 1-5 shows the change in real output in each industry sector for the same period. Gains in output in many products were impressive. Real output in nonelectrical machinery, for example, more than doubled over this 10-year period. Output in electric and electronic equipment, transportation equipment (other than motor vehicles), instruments and related products, and chemicals and allied products rose by about 50 percent during that period.[22]

The United States also continues to exhibit considerable strength in exports of manufactured and high-technology goods.[23] By 1988, the United States retained a 20 percent share of world exports of technology-inten sive products, although the total share had fallen slowly since the 1970s.[24] In this area, U.S. performance, relative to its historical postwar record, continues strong. The 1991 merchandise trade balance for high-technology products totaled $36.7 billion. This compares to a deficit of $102.9 billion for all other U.S. merchandise trade.

In sum, it is important to note that, contrary to many other assessments of U.S. technological performance, we find that the United States continues to exhibit considerable strength in a wide range of industrial sectors, as evidenced in part by an analysis of the data on both industrial output and exports. There is no systematic erosion of the nation's advantages in global markets or its ability to produce and market high-technology goods and services. Much of the debate over competitiveness during the 1980s was driven by concern about the U.S. trade balance, particularly trade in manufactures. A brief summary of the developments that led to the large trade deficits during this period is illustrative.

The primary factor that contributed to growth in U.S. trade deficits during the 1980s is accounted for by imbalances in domestic consumption, savings, and investment patterns. The U.S. trade deficit is a product of macroeconomic forces in the economy. The combination of a decline in domestic savings and high levels of consumption, reflected in the strong growth in imports, contributed to the large deficits in trade from 1982 to 1987.

Macroeconomic forces in the United States during the early 1980s also contributed to the rapid appreciation in the value of the dollar against other currencies in international markets (more than 60 percent during the early 1980s). The real effective exchange rate for the dollar rose from 85 in 1981 (March 1973 = 100) to a high of approximately 150 in early 1985.[25] Although it has since fallen to the level of 1981, the impact of this extended period of high-value and the resulting price increases of U.S. goods in world markets undoubtedly contributed to the sharp rise in the trade deficit.

Most importantly, during this period, foreign (as well as domestic) consumers were exposed to less expensive and in some case higher-quality goods from countries other than the United States. The long-term implications of this shift in consumption patterns, facilitated in part by the rapid appreciation of the dollar in the first half of the 1980s, are unclear. This is especially true with respect to the ability of U.S. firms to recapture markets that may have been lost during this period.

Although U.S. exports today, particularly in manufactures, are strong, foreign competition continues to improve, especially for high-technology end products and processes. Foreign competition, moreover, is increasingly based on the returns to high levels of industrially funded investment in R&D and growing public investments in research, technology development, and education.

TABLE 1-3 Gross National Product by Industry (billion 1982 dollars)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Gross National Product	3,115.2	3,192.4	3,187.1	3.248.8	3,166.03	3,279.1	3,501.4	3,618.7	3,717.9	3.717.9	4,024.4
Domestic industries (Gross Domestic Product)	3,073.0	3,136.6	3,131.7	3,193.6	3,114.8	3,231.2	3,457.5	3,581.9	3,687.4	3,827.2	3,996.3
Manufacturing	694.7	712.2	673.9	678.6	634.6	674.2	752.4	779.2	803.2	849.7	927.5
Durable goods	423.3	433.1	408.5	408.6	362.5	383.8	448.6	471.5	482.7	517.4	583.2
Lumber and wood products	19.3	21.7	21.3	16.5	16.0	18.8	20.9	19.8	21.3	24.2	25.7
Furniture and fixtures	11.1	10.9	10.4	10.2	9.5	10.4	11.6	12.1	12.0	12.8	12.3
Stone, clay, and glass products	23.3	23.5	21.3	20.2	18.2	19.7	21.3	22.2	22.9	24.9	25.2
Primary metal industries	52.8	52.7	48.2	50.6	35.3	28.9	33.4	32.7	32.2	34.6	37.9
Fabricated metal products	53.4	56.0	53.7	53.0	46.3	48.8	54.8	56.2	54.8	58.4	63.2
Machinery, except electrical	80.9	85.6	86.1	89.6	80.0	84.8	105.7	124.21	29.4	140.7	170.5
Electrical and electronic equipment	56.2	60.2	63.3	64.9	61.8	64.6	73.5	74.37	4.1	78.3	88.1
Motor vehicles and equipment	58.1	51.6	35.2	34.8	29.5	37.8	47.3	50.3	46.5	46.4	51.7
Other transportation equipment	34.9	36.5	37.4	33.1	32.2	37.6	41.3	42.5	49.8	55.5	60.9
Instruments and related products	20.3	22.4	21.9	23.8	22.6	23.1	25.2	24.2	25.7	26.7	31.5
Miscellaneous manufacturing industries	13.0	12.0	9.7	12.1	11.1	9.5	13.7	13.0	14.0	15.0	16.1

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Nondurable goods	271.4	279.0	265.5	269.9	272.1	290.4	303.8	307.7	320.5	332.2	344.3
Food and kindred products	56.6	59.5	59.8	58.9	61.4	62.7	62.1	64.8	65.6	66.5	67.8
Tobacco manufactures	9.9	9.9	9.6	9.9	8.9	8.0	7.8	6.2	7.0	5.6	4.7
Textile mill products	16.6	17.0	16.4	15.8	14.8	16.2	16.0	15.6	17.0	17.3	16.8
Apparel and other textiles	21.5	21.3	21.1	20.3	18.9	20.1	20.4	20.1	21.0	22.7	23.2
Paper and allied products	28.9	28.7	25.8	25.5	26.7	29.0	29.5	30.2	31.6	33.8	34.9
Printing and publishing	36.2	37.1	37.0	38.6	38.4	39.6	40.8	42.5	43.1	43.6	45.5
Chemicals and allied products	55.1	56.7	50.0	54.0	55.3	59.7	59.4	59.1	64.6	68.2	74.2
Petroleum and coal products	22.7	24.9	22.9	21.8	24.4	29.83	9.5	39.4	41.1	42.6	44.6
Rubber and miscellaneous plastic products	19.0	19.7	18.6	20.8	19.3	21.6	24.7	26.6	26.7	29.3	29.8
Leather and leather products	4.9	4.2	4.3	4.4	4.1	3.8	3.6	3.2	2.7	2.8	2.9

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business*, January 1991, Table 6, p. 34.

TABLE 1-4 Real Output by Industry as a Percentage of Total Gross National Producta

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Manufacturing	22.30	22.31	21.11	20.89	21.30	20.56	21.49	21.53	21.60	22.85	23.05
Durable goods	13.59	13.57	12.82	12.58	11.45	11.70	12.81	13.03	12.98	13.92	14.49
Lumber and wood products	0.62	0.68	0.67	0.51	0.51	0.57	0.60	0.55	0.57	0.65	0.64
Furniture and fixtures	0.36	0.34	0.33	0.31	0.30	0.32	0.33	0.33	0.32	0.34	0.31
Stone, clay, and glass	0.75	0.74	0.67	0.62	0.57	0.60	0.61	0.61	0.61	0.67	0.63
Primary metal industries	1.70	1.65	1.51	1.56	1.11	0.88	0.95	0.90	0.87	0.93	0.94
Fabricated metal products	1.71	1.75	1.68	1.63	1.46	1.49	1.57	1.55	1.47	1.57	1.57
Machinery, except electrical	2.60	2.68	2.70	2.76	2.53	2.59	3.02	3.43	3.48	3.78	4.24
Electrical and electronic equipment	1.80	1.89	1.99	2.00	1.95	1.97	2.10	2.05	1.99	2.11	2.19
Motor vehicles and equipment	1.87	1.62	1.10	1.07	0.93	1.15	1.35	1.39	1.25	1.25	1.28
Other transportation equipment	1.12	1.14	1.17	1.02	1.02	1.15	1.18	1.17	1.34	1.49	1.51
Instruments and related products	0.65	0.70	0.69	0.73	0.71	0.70	0.72	0.67	0.69	0.72	0.78
Miscellaneous manufacturing industries	0.42	0.38	0.30	0.37	0.35	0.29	0.39	0.36	0.38	0.40	0.40

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Nondurable goods	8.71	8.74	8.33	8.31	8.59	8.86	8.68	8.50	8.62	8.94	8.56
Food and kindred products	1.82	1.86	1.88	1.81	1.94	1.91	1.77	1.79	1.76	1.79	1.68
Tobacco manufactures	0.32	0.31	0.30	0.30	0.28	0.24	0.22	0.17	0.19	0.15	0.17
Textile mill products	0.53	0.53	0.51	0.49	0.47	0.49	0.46	0.43	0.46	0.46	0.42
Apparel and other textiles	0.69	0.67	0.66	0.62	0.59	0.61	0.58	0.56	0.56	0.61	0.58
Paper and allied products	0.93	0.90	0.81	0.78	0.84	0.88	0.84	0.83	0.85	0.91	0.87
Printing and publishing	1.16	1.16	1.17	1.19	1.21	1.21	1.17	1.17	1.16	1.17	1.13
Chemicals and allied products	1.77	1.78	1.57	1.66	1.75	1.82	1.70	1.63	1.74	1.83	1.84
Petroleum and coal products	0.73	0.78	0.72	0.67	0.77	0.91	1.13	1.09	1.16	1.15	1.11
Rubber and miscellaneous plastic products	0.61	0.62	0.58	0.64	0.61	0.66	0.71	0.74	0.72	0.79	0.74
Leather and leather products	0.16	0.13	0.13	0.13	0.13	0.12	0.10	0.08	0.07	0.08	0.07

[a] 1982 constant dollar basis. For GNP in 1982 constant dollars, see Table 1-3.

SOURCE: Calculated from data contained in U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business,* January 1991, Table 6, p. 34.

TABLE 1-5 Change in Real Output by Industry

	Change (billion 1982 dollars)		Change (percent)
	1978	1988	
Gross National Product	3,115.2	4,024.4	29.2
Domestic industries (Gross Domestic Product)	3,073.0	3,996.3	30.5
Manufacturing	694.7	927.5	33.5
Durable goods	423.3	583.2	37.8
Lumber and wood products	19.3	25.7	33.2
Furniture and fixtures	11.1	12.3	10.8
Stone, clay, and glass products	23.3	24.9	6.9
Primary metal industries	52.8	37.9	-22.2
Fabricated metal products	53.4	63.2	18.4
Machinery, except electrical	80.9	170.5	110.8
Electrical and electronic equipment	56.2	88.1	56.8
Motor vehicles and equipment	58.1	51.7	-11.0
Other transportation equipment	34.9	60.9	74.5
Instruments and related products	20.3	31.5	55.2
Miscellaneous manufacturing industries	13.0	16.1	23.8
Nondurable goods	271.4	344.3	26.9
Food and kindred products	56.6	67.8	19.8
Tobacco manufactures	9.9	4.7	-52.5
Textile mill products	16.6	16.8	1.2
Apparel and other textiles	21.5	22.7	5.6
Paper and allied products	28.9	34.9	20.8
Printing and publishing	36.2	45.5	25.7
Chemicals and allied products	55.1	74.2	34.7
Petroleum and coal products	22.7	44.6	96.5
Rubber and miscellaneous plastic products	19.0	29.8	56.9
Leather and leather products	4.9	2.9	-40.8

SOURCE: Calculated from data contained in U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business,* January 1991, Table 6, p. 34.

The indicators outlined above do not allow a precise determination of whether U.S. strengths in technology commercialization have declined relative to their earlier levels. Almost certainly, however, U.S. performance in these areas now is being challenged more strongly than ever before as a result of improvements in the capabilities of foreign firms. In some cases, we believe, problems in the United States reflect the failure of U.S. firms in mature industries to successfully exploit advanced technologies.

In the panel's judgment, obstacles to improvements in technology commercialization are closely linked to weaknesses in technology adoption. Anecdotal evidence suggests that even when U.S. firms adopt these technologies early in the production cycle, they encounter greater difficulties, relative to some foreign firms, in exploiting the potential of new process technologies to improve productivity and product quality.[26] Especially in manufacturing process technologies, the limited data available suggest that U.S. firms lag behind some foreign competitors in the rate of adoption and the intensity of utilization of such technologies as computer-integrated manufacturing, numerically controlled machine tools, and robotics.[27] This fact is especially true for small and medium-sized firms.

One study of U.S. metalworking factories found that only 10 percent of small plants used numerically controlled machines tools, far below the 83 percent of large plants that did so.[28] An indication of the disparity in technology adoption between large manufacturers and small or medium-sized ones is the apparent gap in the United States between "best-practice" and "average-practice" firms.[29] Thus U.S. technological performance is challenged less in the creation of new technologies than in their commercialization and adoption. Over the longer term, however, the ability of this nation to sustain high levels of investment (from public and private sources) in the scientific enterprise will be affected heavily by the overall performance of the U.S. economy.

Data on U.S. and foreign performance in the commercialization of technologies are difficult to obtain. As the discussion above indicates, many U.S. firms, individuals, and universities are very successful producers of new inventions on which commercial innovations are based. Nevertheless, recent reports by expert committees have expressed concern over U.S. performance in technology commercialization.[30] In products such as semiconductor memory components, U.S. firms' early mastery of the product and process technology, links to advanced university research, and early dominance of the market did not translate into sustained competitive strength in these products, although the United States continues to exhibit strength in many advanced semiconductor products. Some companies in the automobile, consumer electronics, steel, and other industries have faced problems similar to those in the semiconductor industry.[31] In many cases, U.S. firms have demonstrated weaknesses in their ability to maintain strength in the "complementary" skills and assets needed to sustain a competitive advantage, most notably by failing to maintain state-of-the-art manufacturing technologies.

There is another set of clearly identifiable problems apparent in U.S. industry, which should not be confused with the commercialization of product and process technology. These weaknesses are directly related to design for manufacturability, quality, just-in-time inventory control, and manufacturing process capacities, and to relationships between firms and suppliers. They are often associated with the technology adoption process outlined above. Some U.S. firms have also failed to compete successfully in "cyclical" innovation processes, moving too slowly to incorporate new technologies into improved versions of established products.[32]

The primary responsibility for making improvements in increasing quality, building more productive relationships with suppliers and vendors, and improving design for manufacturability rests with the private sector. These areas are not associated with advanced technology creation or pre-commercial R&D work, the major focus of this report. They need to be recognized, however, as an important part of any program to improve U.S. economic performance.

This report centers on methods to strengthen the U.S. capacity in technology beyond basic research, in particular the federal role in supporting technological advance in pre-commercial areas. The recommendations for change are based on the conclusion that we can leverage U.S. strengths in research to compete even more vigorously in international markets, but only with higher levels of investment (through both public and private funding) in work that eventually leads to more rapid technology commercialization rates in U.S. industry.

Innovation is a continuum, with feedback among all stages in the process, from technology creation through to the commercialization and adoption of new technologies. It should be recognized as such. Higher levels of investment in the critical pre-commercial stage of technology development will enhance U.S. performance in technology commercialization over the long-term. To a significant degree, the postwar advantages of the United States in the research and technology creation processes have been supported (indeed, some would say that they were created) by federal policy. As noted below, however, the postwar focus of federal policy requires change. We now turn to a brief overview of the central components of this policy structure and a discussion of the changes in the economic and technological environment that have weakened its economic payoffs.

THE STRUCTURE OF POSTWAR U.S. SCIENCE AND TECHNOLOGY POLICY

The key elements of federal science and technology policy arose during World War II and the following Cold War period.[33] In general, this policy framework is characterized by loose coordination among R&D investment and other activities of a large number of federal agencies. Neither the executive nor the congressional branch of the federal government reviews the allocation, costs, and benefits of the entire federal R&D budget on a regular basis. The interaction between science and technology policies and other policy areas (e.g., antitrust and trade) also is rarely reviewed on any but a sporadic basis.

Other key characteristics of postwar U.S. technology policy and the U.S. innovation system that differentiate the United States from most industrialized economies include the following:[34]

1. *Dominance of the large federal R&D budget by defense and related agencies:* Throughout the postwar period, federal funds have accounted for a large share (between 45 and 60 percent) of total national R&D spending. The federal R&D budget has in turn been dominated by defense-related expenditures, whose effects on commercial technologies and the firms marketing them were accentuated during the 1950s and 1960s by large-scale military procurement of components and systems in areas such as computers and microelectronics. In some instances, the combined effects of "spillovers" and military procurement policy supported the development of commercial applications.
2. *The prominent role of U.S. universities as performers of research, especially basic research, most of which is funded from federal sources:* A large share of the basic research performed in the United States, more than 50 percent in recent years, is carried out in universities. In the United States, universities account for a larger share of total national R&D performance than in Western Europe or Japan, although direct comparisons of what each nation defines as research and development are difficult.
3. *Minimal assistance for industrial technology adoption*: With the significant exception of agriculture, the large federal investment in military and civilian research and technology development provides virtually no support for the adoption of new technologies. In this respect, as Ergas has pointed out,[35] postwar U.S. policy resembles that of France and the United Kingdom, both of which supported large defense-related R&D budgets, and contrasts with the policies of Germany, Sweden, and Japan, where a larger investment of public resources was directed to facilitating technology adoption.

Current U.S. technology policy relies primarily on federal funding of scientific research, especially basic research. It also includes an emphasis on funding of applied research and development in defense, nuclear power, and space-related technologies. The postwar policy of the United States is also differentiated from that of many other industrial economies by the prominent role federal procurement policies have played in the development of the defense, telecommunications, and transportation sectors, among others.

The resulting system for the creation, commercialization, and adoption of new technologies is diverse in terms of funding sources, performers, and objectives. It also links scientific research more closely to postgraduate education than is true of other industrial economies. In addition, the U.S. technological system is affected (as are other nations') by the structure of financial markets, firm size and ownership, and corporate management and oversight. There are significant differences between the United States and other industrialized countries in these areas, as well.

There are many new challenges to national technology performance, as based on the framework outlined above. These developments have intensified international competition, while at the same time creating new opportunities for U.S. firms to sell goods and services in an increasingly large global market. In our judgment, this new environment may have also reduced the economic payoffs to U.S. firms and citizens from the large federal investment in R&D. This is true even though research investment benefits both the United States and other nations, and any restriction on the diffusion of scientific research is a potentially costly and dangerous exercise.

The globalization of formerly national technical enterprises, dispersion of corporate R&D and manufacturing facilities, rising costs of R&D efforts, and shortened time horizons for the introduction of new products and processes all create special challenges for U.S. firms. Important changes in the global economy over the past two decades are related to the growth of world trade and its increased importance to U.S. industry. The growth of international trade has produced significant economic benefits to the United States through rising levels of income as the nation specializes in producing goods and services in which it enjoys a comparative advantage. International trade has doubled as a share of U.S. GNP over the past two decades, with imports rising to about 15 percent of total GNP and exports to 12 percent.

Merchandise imports have grown over the past decade with the rapid expansion of domestic spending relative to GNP, increasing about 100 percent between 1980 and 1990 from $253 billion to $518 billion. In 1982 constant dollars, exports have risen at an even more rapid rate. From 1980 to 1990, for example, U.S. merchandise exports alone grew by about 75 percent, from $241 billion to $424 billion.[36] Moreover, export expansion over the past five years (1986–1991) has accounted for 37 percent of U.S. growth (real) in GDP.[37]

The growth of international trade, as well as the increased pace at which capital and technology move across national borders, poses significant challenges to U.S. industry. U.S. manufacturers now compete with technologically sophisticated foreign firms in an international marketplace—at home as well as abroad. This is happening even as U.S. exports depend more than ever on R&D-intensive goods for further export expansion and as competitors challenge the United States in several important high-technology sectors. No longer can U.S. firms rely on producing solely for the domestic market. The world economy now represents a total global demand for goods and services that is four times greater than U.S. domestic demand.

The rising technological competence of foreign firms is one reason the rate of technology diffusion across international boundaries has increased. Some foreign firms are better able to absorb technology from multiple sources, and transnational corporations continue to establish R&D and manufacturing facilities around the world. Technology that was once appropriable (able to be used exclusively) by the innovator in one country is now transferred and diffused throughout the global economy with much greater ease.

Part of the trend toward globalization of economic and industrial activity is evident in the dispersion of transnational corporate R&D and manufacturing facilities. Companies have decentralized technology development assets in response to intensified international competition and the expansion of international opportunity. IBM, Texas Instruments, and Motorola have established facilities in Japan and Europe, for example, whereas Sony, NEC, and Philips have established operations in the United States. The number of R&D laboratories located outside a corporation's home base has grown substantially. Through investment and acquisitions in foreign firms, companies have expanded facilities overseas to strengthen the integration of product development, design, and marketing capabilities.[38]

The increasingly international character of research and innovation has evolved for many reasons. In part, this has taken place in response to the need to locate operations close to foreign markets and to reduce market-specific product development and manufacturing times as product life cycles shorten. In some cases, protectionist trade or technology policies have contributed to the location of R&D facilities outside the borders of a corporation's home base. The homogenization of world demand, especially with regard to technologically advanced products, has also shaped corporate decisions on the location of facilities overseas. Finally, advances in technology itself, including less costly and more advanced telecommunications and transportation systems, among others, have moved the world toward closer integration. All of these factors have heightened international competition and complicated U.S. industry's R&D and commercialization efforts.

Another dimension of the changing environment for technology development is the rising cost of R&D and product development in a number of key technology-intensive industries. Over the past two decades, the costs of bringing new products and processes to market have risen sharply in the commercial aircraft, semiconductor, computer, and telecommunications industries. For example, it is estimated that a 4-megabyte (Mb) Dynamic Random Access Memory (DRAM) semiconductor production facility costs in excess of $400 million, not including the expenses associated with product development. For a 16-Mb production facility, the costs rise to an estimated $700 million, with product development adding another $300 million.[39] Rising costs not only have contributed to the increased importance of export markets but have also encouraged the formation of cooperative R&D ventures.

Costs for R&D and commercialization efforts in many technology-intensive sectors have risen for many reasons. In part, this is due to the fact that firms often need to incorporate expertise in multiple fields into their R&D efforts. The rapid rate of technical change in many R&D areas puts added financial pressure on firms that require long lead times to develop products. For example, technology integration in the computer and telecommunications sectors and biotechnology processes as applied in new drug development mean that companies now must possess the capabilities to incorporate scientific and technical advances in a wide range of technical disciplines. Firms must invest funds in plant and equipment that often quickly become obsolete, and they are forced to capture returns on investment in R&D and capital equipment over shorter payback periods.

Another characteristic of the new technological environment is the growth in technical alliances between firms. Technology cooperation now extends beyond the sharing of technical information or joint production agreements. It increasingly involves joint research and development projects. These projects often form an important part of corporate strategic planning in the microelectronics, aviation, and telecommunications sectors, for example. Technical alliances also are increasingly being forged across national boundaries. In part, this makes it much more damaging to establish a strictly national or "self-sufficient" approach toward technology development.

Moreover, military-funded R&D and defense procurement are becoming less important sources of civilian technology. The celebrated examples of semiconductors, computers, jet engines, and airframes in the 1950s and 1960s, technologies in which military R&D and procurement yielded important civilian applications, have few contemporary counterparts. Military procurement has declined as a share of total demand in many sectors. Tech nologies and applications now increasingly flow from the civilian to the military sector. This change in technology flow has an important economic component. Some U.S. defense suppliers of high-technology components or systems are now economically dependent on their success in civilian markets.[40]

Postwar federal science and technology policies were not designed primarily to aid the capabilities of U.S. firms to commercialize new civilian technologies.[41] Nevertheless, U.S. firms benefitted from the large federal R&D investment because of the relatively slow pace with which the results of this investment moved across international boundaries. Even when such movement occurred, many foreign firms were not well equipped to use these results quickly in commercial applications. These conditions do not apply today. Scientific and technological knowledge move more quickly in the international economy because foreign firms have improved their capabilities to absorb R&D and technology. They are also better able to apply advanced scientific or technological knowledge to the manufacturing process. In addition, as R&D costs and risks increase, access to foreign markets is increasingly important to the viability of U.S. high-technology firms. This is true even as these firms, in many instances, now derive a larger share of their components or advanced subassemblies from foreign sources.

Economic and technological advancement in Japan and Germany, among other countries, has improved rapidly compared to the post-World War II era. Other nations that have not been considered among the front rank of international competitors have proved to be strong exporters in specific markets. Data on the number of scientists and engineers engaged in R&D overseas also indicate the strength and growing capacity of other nations.[42] The per capita level of scientists and engineers working on R&D-related activities in Japan and Europe is reaching U.S. levels. In 1965, Japan had approximately 24 scientists and engineers engaged in R&D work per 10,000 people in the labor force. By 1986, there were 67.4 Japanese scientists and engineers per 10,000 workers, approximately equal to the concentration of R&D scientists and engineers in the United States. As Japan and other nations make progress in providing training and high-value-added employment opportunities for scientists and engineers, they will become even more able competitors.

Productivity growth rates in manufacturing also attest to the improved base upon which the capacity to generate and commercialize new products and processes in other nations is being constructed. Table 1-6 shows output per hour for manufacturing in 14 countries. In Japan, manufacturing productivity has risen sharply since 1960. From 1960 to 1989, the average annual growth rate was 7.6 percent; in the United States, growth averaged 2.9 percent during the same period. Japanese manufacturing productivity growth (5.5 percent) also exceeded that of the United States (3.4 percent) between 1979 and 1987. Productivity in Italy and the United Kingdom in the 1980s also rose at a faster rate than it did in the United States.

TABLE 1-6 Average Annual Rates of Change in Manufacturing Output per Hour

Country	1960-1989	1960-1973	1973-1989	1973-1979	1979-1989	1979-1987	1988	1989
United States	2.9	3.3	2.6	1.6	3.2	3.4	2.3	2.0
Canada	3.1	4.5	1.9	2.1	1.8	1.7	1.7	2.2
Japan	7.6	10.3	5.5	5.5	5.5	5.5	4.7	5.8
Korea	NA	NA	NA	NA	NA	NA	NA	NA
Taiwan	NA	NA	NA	NA	NA	NA	NA	NA
Belgium	6.2	6.9	5.5	6.0	5.1	5.2	4.9	NA
Denmark	4.2	6.4	2.4	4.2	1.4	1.0	3.2	3.0
France	5.0	6.4	3.8	4.6	3.4	3.0	5.1	4.7
Germany	4.1	5.7	2.8	4.2	2.0	1.4	4.5	4.5
Italy	5.4	6.4	4.6	5.7	4.0	4.2	2.8	2.9
Netherlands	5.7	7.3	4.3	5.4	3.7	3.4	4.6	4.5
Norway	3.6	4.7	2.7	2.1	3.0	2.6	2.9	6.4
Sweden	4.2	6.4	2.4	2.6	2.2	2.4	1.4	1.6
United Kingdom	3.8	4.2	3.4	1.2	4.8	4.7	5.4	5.1

SOURCE: Bureau of Labor Statistics.

Rising receipts and payments for patents and technical knowledge also indicate improvements in the technological strength of other nations. Data on royalties and fees are one indication of the global demand for a country's technology and intellectual property. They include payments for product and process inventions, copyrights, and other rights to use technology generated elsewhere. Table 1-7 shows U.S. receipts and payments (royalties and fees), over the period 1972 to 1988, from Japan, the United Kingdom, and Germany. The United States continues to exhibit considerable strength in technology output, based on this indicator.

Japan, in contrast, continues to be a net importer of technology. It has improved its ability to generate technological output, however, as evidenced in the data on royalties and fees for domestically generated technology. Receipts as a share of payments in Japan more than doubled, from 14 to 30 percent of the total, from 1970 to 1985. The United States has been increasing its payments to Japan through royalties and fees. In 1972 the United States made $6 million in yearly payments of royalties and fees to Japan. By 1988 the figure had risen to $112 million.[43]

It is important to note that improvement in the technological and com

TABLE 1-7 U.S. Receipts and Payments of Royalties and Fees Associated with Unaffiliated Foreign Residents, 1972-1988 (millions of dollars)

Year	All Countries	West Germany	United Kingdom	Japan
Receipts				
1972	655	56	63	240
1973	712	63	75	273
1974	751	78	71	249
1975	757	81	79	219
1976	822	83	72	246
1977	1,037	92	82	275
1978	1,180	119	93	343
1979	1,204	109	102	343
1980	1,305	145	113	403
1981	1,490	101	119	423
1982	1,669	105	122	502
1983	1,679	136	134	523
1984	1,709	127	133	549
1985	1,899	112	126	606
1986	1,842	114	112	679
1987	2,170	135	111	875
1988	2,416	126	127	1,016
Payments				
1972	139	29	44	6
1973	176	37	53	13
1974	186	34	67	12
1975	186	32	76	9
1976	189	34	77	13
1977	262	31	72	16
1978	277	27	84	15
1979	309	40	93	15
1980	297	61	96	20
1981	289	43	99	37
1982	292	35	94	31
1983	318	35	90	53
1984	359	59	85	63
1985	425	47	123	66
1986	460	87	76	113
1987	522	108	97	104
1988	1,080	131	143	112

Year	All Countries	West Germany	United Kingdom	Japan
Balance				
1972	516	27	19	234
1973	536	26	22	260
1974	565	44	4	237
1975	571	49	3	210
1976	633	49	(5)	233
1977	775	61	10	259
1978	903	92	9	328
1979	895	69	9	328
1980	1,008	84	17	383
1981	1,201	58	20	386
1982	1,377	70	28	471
1983	1,361	101	44	470
1984	1,350	68	48	486
1985	1,474	65	3	540
1986	1,382	27	36	519
1987	1,648	27	14	750
1988	1,336	(5)	(16)	904

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis data, as reported in *International Science and Technology Data Update: 1991*, National Science Foundation, Special Report, NSF 91-309, p. 117.

petitive capabilities of foreign firms is by no means a negative development. Indeed, by improving the quality of products and processes available to U.S. consumers (which include U.S. industrial firms that utilize foreign-source technologies and components), this development will improve U.S. standards of living, not erode them. As incomes rise overseas with increased technical, manufacturing, and export competence, aggregate levels of income in the United States rise, and demand for the nation's goods and services also increase. Moreover, rising standards of living overseas reflect the success of postwar U.S. policies that supported reconstruction and economic development. The U.S. economy benefits from innovations wherever they are generated. If, however, we can devise policies and programs that serve to improve U.S. performance, our standards of living will benefit more than if we do not act. Moreover, if the nation's capacity to commercialize and market goods and services (particularly high-technology manufactures) is improved from its current performance, it will benefit the economy over the long-term.

In sum, the developments in recent years that, in the panel's view, form a basis for carefully reviewing federal policy toward civilian technologies are (1) the increased exposure of U.S. firms to more intense international competition from more capable foreign firms, as well as their expanded opportunities in foreign markets; and (2) some decline in the ability of U.S. firms to derive economic benefits from the large federal investment in basic and defense-related R&D. These developments may, we believe, have reduced the technological lead of U.S. firms in terms of their ability to apply and adopt new technologies. These developments also may have increased the difficulties faced by U.S. firms in capturing high returns on investments in technology creation and commercialization.

OTHER POLICY ISSUES

A central theme of this report is the need to recognize the breadth of the array of policies and factors that influence technological performance. Many of these policies lie outside the group of instruments typically associated with science and technology policy. For example, capital requirements of technology creation, commercialization, and adoption are such that the domestic economic environment for capital formation is an important influence on technological performance. A cost of capital to U.S. firms that greatly exceeds the cost faced by foreign competitors would, over time, have a significant influence on investment decisions. These in turn will affect the processes of technology creation (through diminished expenditures on research, the returns from which may not be realized for many years), commercialization (reduced expenditures on development, plant, and equipment, etc.), and adoption (reduced investments in capital goods that embody new technologies).

To the extent that the cost of capital facing U.S. corporations may now exceed costs overseas (a point on which there is currently a lack of consensus), it suggests differences between the United States and other countries in a number of areas, including interest rates, tax structures, and operation of financial markets. A detailed examination of these factors is beyond the scope of this report; however, the apparent short-term focus of U.S. managers on investments in physical capital and R&D (whatever its causes) is a central concern.[44] Moreover, for the recommendations of this panel to have any impact, U.S. firms must improve their management of technological assets. In the context of current public policies, U.S. managers have, in some cases, failed to manage these resources carefully or effectively. In other instances, they have failed to respond adequately to international competition and have been inattentive to technological and scientific advances not invented in their own firms. In addition, internal compensation and incentive practices have rarely rewarded managers who pursued careers in engi neering design and production. Compensation is greatest for those in marketing, finance, and even research and development.

Given the current environment in which managers operate, they should seek to create an atmosphere within their firms that supports long-term investment. Investments should focus on R&D, improving manufacturing performance, and enhancing employee skills. Senior managers of U.S. firms can no longer assume that they can compete in today's global economy without a deep understanding of the technological strengths, weaknesses, and needs of their firms, as well as domestic and foreign competitors. Management and engineering schools in the United States must also improve their performance in educating students on technology management and manufacturing issues.

Another area in which U.S. public policy and private investment decisions appear to be handicapping its technological performance is investment in the skills of the work force. This is true for both those entering the labor force and workers currently employed (or displaced). The U.S. higher education system remains strong, despite growing financial pressures on U.S. universities. The same cannot be said, however, of U.S. public primary and secondary education. The U.S. system appears to perform less well than educational systems in other industrial and some industrializing economies, particularly in equipping entrants to the work force with basic abilities in literacy, numeracy, science, and mathematics.

Job-related proficiency in many industries now centers on these abilities. In addition, they are often the foundation necessary for workers to make the transition to new jobs or to work with new technologies. The public and private institutions that support the transition from secondary school to the workplace in the U.S. economy are unequal, we believe, to the task. Programs to improve the skills of the employed work force and workers facing displacement also are considerably weaker in the United States than in Japan and Germany.[45] In Japan, the central government and industrial firms emphasize programs that encourage all new engineers to begin training cycles on the shop floor. In Germany, apprentice systems allow workers to move into higher skill-based jobs, and the federal government supports the training of technicians. Both countries have undoubtedly benefitted from these and other efforts to enhance work force skills and training.

Improvements in U.S. technological performance will require steps by the private sector and by federal, state, and local governments to improve public primary and secondary education, with a strong emphasis on basic skills—literacy and numeracy. Investment in the skills of the employed work force, and investment in retraining the unemployed or imminently unemployed worker, are also important to the long-term technological performance of U.S. firms.

A final area in which public agencies carry an especially significant burden is in the provision of the physical infrastructure necessary to support highly productive economic activities. Here, too, the performance of federal, state, and local governments in recent years has been poor. Data on trends in U.S. investment in infrastructure show declining rates of investment during the 1970s and 1980s, relative to past decades. Not only has the rate of growth in the value of capital stock declined, particularly in the nonmilitary sector, but recent assessments show a reduced federal role in investments in infrastructure. From 1960 to 1987, federal support for capital investments, operations, and maintenance in infrastructure fell from 31 to 24 percent of total federal government expenditures.[46] During the same period, the proportion of all government spending in the United States (federal, state, and local) allocated to public works projects in infrastructure fell from 12 to 7 percent.

Evidence for a relationship between investment in infrastructure and economic development is both intuitive and analytical. Moreover, the relationship is an interactive one—slower productivity growth implies slower growth in national income and reduced rates of growth in public revenues to support these expenditures. It seems evident that the growth of industry sectors such as automobiles and air transportation rested in large part on massive public investments in highways, airports, and air safety. Conversely, crumbling roads, collapsed bridges, and congested airports today seem to threaten afflicted regions with economic disruption. The panel supports efforts to increase levels of investment in the physical infrastructure of the U.S. economy.

SUMMARY AND CONCLUSIONS

The poor U.S. performance in improving measured productivity growth rates is a central cause for concern. This is particularly true when considering the economic environment for technology development in the United States. As we have seen, investment in physical capital and civilian research and development are important components of strong productivity growth rates. These are areas to which we must devote greater attention in the future. In addition, we have found that the innovative capacity of the United States through the development stage has remained strong relative to the nation's performance over the past several decades. There are many indications of continuing U.S. strengths as they relate to innovation and technology development, including a strong university system and basic research enterprise, U.S. dominance in generating technologies with potential commercial value, and strong real rates of growth in output of the manufacturing sector.

Nonetheless, the economic and technological challenge posed by our major competitors has increased dramatically over the past two decades. U.S. firms can improve their performance in moving technology into the now global commercial marketplace (technology commercialization), where they face this challenge, and speed the transfer and adoption of new technologies throughout the economy. Federal government policy can affect industrial performance in these areas.

In addition, problems associated with design for manufacturability, incremental improvements in product and process technology, relations between suppliers and customers, and quality control require attention. These problems have little to do with the commercialization of new, innovative technologies, but progress in raising U.S. performance in these areas is critical to long-term economic advance. The time required to go from product design to commercialization in some important U.S. industries significantly exceeds that of foreign competitors, for example. The new competitive environment for technology development means that continuous improvements by U.S. firms in manufacturing process technology will be necessary. Progress here remains primarily a private sector responsibility.

The panel believes, however, that modifications in federal technology policies can also strengthen national performance in civilian technology and enhance long-term economic growth. The U.S. performance (relative to its past) in technology is being challenged more strongly than ever before in the postwar period. The United States can strengthen technology commercialization, at a stage prior to that at which private firms invest in commercialization activities, through federal action to facilitate pre-commercial R&D. There is a legitimate federal role in this area. The science and technology enterprise is not characterized by a linear model of development, as we have seen. It is an intense, interactive process whereby investment in pre-commercial activities can help promote commercialization and thereby support productivity growth. The United States can construct a technology policy (and design a program) that avoids direct subsidies for firms and industries, while at the same time supporting and leveraging U.S. comparative advantages in technological innovation.

NOTES

1. For an overview of productivity and investment see, John Wilson, "The Contribution of Infrastructure, Human and Physical Capital, and R&D Investments to Productivity Growth" (Paper prepared for the Science, Technology, and Economic Policy Board, National Research Council, Washington, D.C., March 1991).
2. Eugene Kroch, "Recent Real Income and Wage Trends in the United States," *Federal Reserve Bank of New York Quarterly Review* 16 (Summer 1991):36-39.
3. Steven Englander and Axel Mittelstadt, *Total Factor Productivity* (Paris: Organization for Economic Cooperation and Development, 1988), 8.
4. The administration has requested $26 million in fiscal year 1992 for a new program to improve the collection and analysis of economic statistics/data by the federal government.

5. Michael J. Boskin and Lawrence J. Lau, "Post-War Economic Growth in the Group of Five Countries: A New Analysis" (Working papers, Department of Economics, Stanford University, 1990).

6. Dale W. Jorgenson, Frank M. Gollop, and Barbara M. Fraumeni, *Productivity and U.S. Economic Growth* (Cambridge, Mass.: Harvard University Press, 1987).

7. Dale W. Jorgenson, "Investing in Productivity Growth," in *Technology and Economics* (Washington, D.C.: National Academy of Engineering, 1991), 59.

8. Studies that attribute flat capital-labor ratios to the productivity slowdown include Otto Eckstein, "Core Inflation, Productivity, Capital Supply, and Demand Management," in *The Economy and The President: 1980 and Beyond*, ed. Walter E. Hoadley (Englewood Cliffs, N.J.: Prentice-Hall, 1980); Richard W. Kopcke, "Capital Accumulation and Potential Growth," in *The Decline in Productivity Growth* (Boston: Federal Reserve Bank of Boston, 1980); M. Ishaq Nadiri, "Sectoral Productivity Slowdown," *American Economic Review*, no.2 (May 1980):349-352; and Peter K. Clark, "Capital Formation and the Recent Productivity Slowdown," (Paper presented to the American Economic Association and the American Finance Association, December 30, 1977), among others. See also Edward F. Denison, "Discussion," in *The Decline in Productivity Growth* (Boston: Federal Reserve Bank of Boston, 1980) and Edward Wolff, "The Composition of Output and the Productivity Growth Slowdown of 1967-76" (New York University, Department of Economics, 1981, Mimeographed), who have argued that capital formation was not a prime factor in productivity growth slowing.

9. See Council of Economic Advisors, *Economic Report of the President 1990* (Washington, D.C.: U.S. Government Printing Office, 1991).

10. Englander and Mittelstadt, *Total Factor Productivity*.

11. G. Perry, "Potential Output and Productivity," *Brookings Papers on Economic Activity*, No. 1 (Washington, D.C.: The Brookings Institution, 1987), 11-47; and Martin Neil Baily, *Brookings Papers on Economic Activity*, No. 1 (Washington, D.C.: The Brookings Institution, 1981).

12. National Science Foundation, *International Science and Technology Data Update: 1988* (Washington, D.C.: National Science Foundation, 1989), 8; and National Science Foundation, *National Patterns of R&D Resources:1989* (Washington, D.C.: National Science Foundation, 1989).

13. See Government-University-Industry Research Roundtable, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *Industrial Perspectives on Innovation and Interactions with Universities* (Washington, D.C.: National Academy Press, 1991) for further discussion of this point.

14. Stephen J. Kline, "Research, Invention, Innovation, and Production: Models and Reality" (Stanford, Calif.: Stanford University, February 1985), 23; and Ralph E. Gomory, "From the 'Ladder of Science' to the Product Development Cycle," *Harvard Business Review* 67 (November-December 1989):99-105.

15. See, for example, Ralph E. Gomory, "Technology Development," *Science* 220 (May 6, 1983):577.

16. See analysis contained in the following working papers of the MIT Commission on Industrial Productivity (Cambridge, Mass.: MIT Press, 1989): Kirkor Bozdogan, "The Transformation of the U.S. Chemical Industry," vol. I, 1-41 and Artemis March, "The U.S. Commercial Aircraft Industry and Its Foreign Competitors, vol. I, 1-51, for example.

17. See, for example, Massachusetts Institute of Technology (MIT), Commission Working Group on Consumer Electronics Industries, "The Decline of U.S. Consumer Electronics Manufacturing: History, Hypotheses, and Remedies," *MIT Commission on Industrial Productivity Working Papers*, vol. I (Cambridge, Mass.: MIT Press, 1989), 76; Artemis March, "The U.S. Machine Tool Industry and Its Foreign Competitors," *MIT Commission on Industrial Productivity Working Papers*, vol. II (Cambridge, Mass.: MIT Press, 1989), 1-109; and Commission Working Group on the Materials Industry, "The Future of the U.S. Steel Industry in the

International Marketplace," *MIT Commission on Industrial Productivity Working Papers*, vol. II (Cambridge, Mass.: MIT Press, 1989), 1-49.

18. The source for much of the information in this section is the National Science Board, *Science and Engineering Indicators-1991* (Washington, D.C.: U.S. Government Printing Office, 1991).

19. There are problems associated with using data on patents as an absolute indicator of the strength of national technical output. In industries such as computers, telecommunications, and other technology-intensive sectors, many of which are still in the formative stages, patents are less important for protection of intellectual property rights (IPR) than other instruments. (For an overview of intellectual property rights issues, including a discussion of the evolving forms of IPR protection, see Robert P. Benko, *Protecting Intellectual Property Rights* (Washington, D.C.: American Enterprise Institute, 1987).) In addition, there are problems associated with interpreting data produced by the U.S. Patent Office. The Patent Office has been subject to budget constraints, shrinking resources devoted to patent applications during the 1980s, and perhaps other special inefficiencies in the granting process. See Zvi Griliches, "Patents: Recent Trends and Puzzles," in *Brookings Papers on Economic Activity, Microeconomics* , eds. Martin Neil Baily and Clifford Winston (Washington, D.C.: The Brookings Institution, 1989), 291-319.

20. Source: National Science Foundation data, as based on Department of Commerce, Bureau of Economic Analysis data and unpublished data.

21. Source: U.S. Department of Labor, Bureau of Labor Statistics data.

22. Other indications of the strength of U.S. manufacturing include data on exports, although a more accurate picture of the relative strength of an industry sector over time rests in part on growth in *real* output. Nonetheless, manufactured exports, at least over the past decade, which are now increasingly important to U.S. economic growth, grew from $200 billion in 1987 (1982 constant dollars) to $315.7 billion in 1990. This represented a 27.8 percent rise from 1987 to 1988, a 12.3 percent rise from 1988 to 1989, and a 10 percent rise from 1989 to 1990.

23. The U.S. Department of Commerce (DOC) ranks products by their R&D intensity and defines those with above-average intensities as technology-intensive. This identification is known as the DOC-2 definition of high-technology products. The DOC-2 industries, together with their standard industrial classification (SIC) codes, are electrical transmission and distribution equipment (SIC 361, 362, 366, and 367); aircraft and parts (SIC 372); office, computing, and accounting machines (SIC 357); drugs and medicines (SIC 283); industrial inorganic chemicals (SIC 281); professional and scientific instruments (SIC 381 and 382); engines, turbines, and parts (SIC 351); plastic materials and synthetic resins, rubber, and fibers (SIC 282); radio-and TV-receiving equipment (SIC 365); agricultural chemicals (SIC 287); and optical and medical instruments (SIC 383-387).

DOC identifies high-technology products as those having significantly higher ratios of direct and indirect R&D expenditures to shipments than other product groups. One method used by DOC is an input-output table to allocate the applied R&D expenditures of intermediate goods producers among the final goods producers. This allocation, when normalized by shipments, permits identification of those groups of products whose total R&D intensity is significantly higher than that of other products. These product groups are known collectively as the DOC-3 high-technology products. These industries, together with their SIC codes are guided missiles and spacecraft (SIC 376); communication equipment and electronic components (SIC 365-367); aircraft and parts (SIC 372); office, computing, and accounting machines (SIC 357); ordnance and accessories (SIC 348); drugs and medicines (SIC 283); industrial inorganic chemicals (SIC 281); professional and scientific instruments (SIC 381 excluding 3825); engines, turbines, and parts (SIC 351); and plastic materials and synthetic resins, rubber, and fibers (SIC 282). The DOC-2 definitions encompasses a wider number of product groups than DOC-3.

24. National Science Foundation, as based on U.S. Department of Commerce, International Trade Administration data.

25. Council of Economic Advisors, *Economic Report of the President, 1990* (Washington, D.C.: U.S. Government Printing Office, 1991), 91; as based on data supplied by the Board of Governors of the Federal Reserve System.

26. See R. Jaikumar, "Postindustrial Manufacturing," *Harvard Business Review* (November-December, 1986), 69. Jaikumar argues that "Rather than narrowing the competitive gap with Japan, the technology of automation is widening it further . . . . With few exceptions, the flexible manufacturing systems installed in the United States show an astonishing lack of flexibility. In many cases, they perform worse than the conventional technology they replace."

27. See MIT Commission Working Group on the Materials Industry, "The Future of the U.S. Steel Industry in the International Marketplace," *MIT Commission on Industrial Productivity Working Papers*, vol. II (Cambridge, Mass.: MIT Press, 1989), 12-18, and Artemis March, "The U.S. Machine Tool Industry and Its Foreign Competitors," *MIT Commission on Industrial Productivity Working Papers*, vol. II (Cambridge, Mass.: MIT Press, 1989), 27; Maryellen R. Kelley and Harvey Brooks, *The State of Computerized Automation in U.S. Manufacturing* (Center for Business and Government, Harvard University, October 1988); and Kenneth Flamm, "The Changing Pattern of Industrial Robot Use," in *The Impact of Technological Change on Employment and Economic Growth*, eds. R. M. Cyert and D. C. Mowery (Washington, D.C.: National Academy Press, 1988); Charles Edquist and Staffan Jacobsson, *Flexible Automation* (Cambridge, Mass.: Blackwell, 1988); and John F. Krafcik and John Paul MacDuffie, *Explaining High-Performance Manufacturing* (Cambridge, Mass.: MIT Press, 1989).

28. John Rees and Raymond Oakey, "The Adoption of New Technology in the American Machinery Industry," *Regional Studies* 18(1984):489-504. Similar findings are in Kelley and Brooks, "The State of Computerized Automation in U.S. Manufacturing"; and Martin Neil Baily and Alok K. Chakrabarti, *Innovation and the Productivity Crisis* (Washington, D.C.: Brookings Institution, 1988), 71-77.

29. The MIT Commission on Industrial Productivity established a set of characteristics held by "best-practice" firms, namely, (1) simultaneous improvements in cost, quality, and delivery, as opposed to trading off one attribute against the other; (2) tight linkages to customers to enable quick response to changes in market demand; (3) tight links to suppliers; (4) integration of technology into multiple aspects of the business environment such as marketing and human resources, as opposed to use of technology for its own sake; (5) fewer levels of bureaucratic hierarchy together with functional integration of corporate divisions; and (6) human resource programs to foster continuous improvements and worker participation and flexibility. Michael L. Dertouzos and Richard K. Lester, *Made in America: Regaining the Productive Edge* (New York: Harper Collins, 1990), 118-128.

30. There is a lack of data and comprehensive analyses of relative rates of technology commercialization in the United States and other industrialized nations. Many expert committees in the United States have, however, produced reports that have identified weaknesses in U.S. performance in technology commercialization and adoption. Expert committee reports that have examined relative U.S. performance in technology, include Dertouzos and Lester, *Made in America*, as well as *The Working Papers of the MIT Commission on Industrial Productivity* , vol. I and II (Cambridge, Mass: MIT Press, 1989); see also Carnegie Commission on Science, Technology, and Government, *Technology and Economic Performance: Organizing the Executive Branch for a Stronger National Technology Base* (New York: Carnegie Commission, 1991). For further discussion of technology adoption, see Kim B. Clark and Takahiro Fujimoto, *Product Development Performance* (Boston: Harvard Business School Press Publishers, 1991); Edwin Mansfield, "Technical Change in Robotics," *Managerial and Decision Economics* Special Issue (Spring 1989):19-25; and C. H. Uyehara, "Appraising Japanese Science and Technology," *Japan's Economic Challenge: Hearings Before the Joint Economic*

Committee, 101st Congress, 2nd Session (Washington, D.C.: U.S. Government Printing Office, 1990), 299-305.

31. See Dertouzos and Lester, *Made in America*.

32. See Gomory, "From the 'Ladder of Science'" and Clark and Fujimoto, *Product Development Performance*.

33. See David C. Mowery, "The Challenge of International Trade and Investment to U.S. Technology Policy" (Paper presented at the National Academy of Engineering symposium on Linking Trade and Technology Policies, Washington, D.C., June 10-11, 1991).

34. Drawn, in part, on David Mowery, "The Challenge of International Trade to U.S. Technology Policy," in *Linking Trade and Technology Policy: International Consequences*, National Academy of Engineering (Washington, D.C.: National Academy Press, forthcoming).

35. See H. Ergas, "Does Technology Policy Matter?" in *Technology and Global Industry: Companies and Nations in the World Economy*, eds. Harvey Brooks and Bruce Guile (Washington, D.C.: National Academy Press, 1987).

36. Office of the U.S. Trade Representative, Executive Office of the President, *Export Growth and the Importance of Fast Track* (Washington, D.C.: Office of the U.S. Trade Representative, 1991).

37. Office of the U.S. Trade Representative, Executive Office of the President.

38. One indication of the rapid growth in the internationalization of R&D is spending by firms on R&D in foreign countries. Data collected by the OECD show, for example, that such spending grew in all OECD countries, except Germany, from 1979 to 1988. By using 1978 to 1979 as a benchmark (1978-1979 = 1.0), expenditures rose to 18 in Italy (due in part to the acquisition of foreign firms), 8.5 in Canada, 4.4 in the United Kingdom, and 2.7 in Japan by 1987-1988. U.S. firms were on the forefront of this trend and accounted for a large part of total R&D spending of foreign firms in OECD countries. Expenditures by U.S. firms rose from $3.2 billion to $6.2 billion from 1980 to 1988. A comparison of spending by foreign companies versus spending by domestic firms on R&D in the home country (foreign as a percentage of domestic expenditures) also shows the rapid expansion of global R&D. For the United States, spending abroad by U.S. industry was 10.5 percent of domestic expenditures by 1988.

Firms have located R&D facilities abroad to capture the benefits of technology scanning and sourcing of foreign scientific and engineering talent. For example, Japanese firms moved rapidly during the 1980s to invest and acquire R&D facilities outside Japan, contributing, in part, to their success in global markets. During the years 1987 to 1990, 33 new R&D centers were established by 20 of the top Japanese firms in the United States (21), Asia (6), and Europe (6).

39. As cited in U.S. Department of Commerce, Advisory Council on Federal Participation in SEMATECH, *SEMATECH, 1990* (Washington, D.C.: U.S. Government Printing Office, May 1990).

40. This changing economic and technological relationship also has increased the economic burden imposed on many U.S. firms by national security export controls, as the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine point out in their report *Finding Common Ground* (Washington, D.C.: National Academy Press, 1991). Similar conclusions were reached in the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *Balancing the National Interest* (Washington, D.C.: National Academy Press, 1987).

41. Indeed, the impressive economic performance of the United States during 1900 to 1940, when scientific research in this nation lagged behind that of a number of European countries, suggests that the link between scientific prowess and national competitiveness may be weaker than generally thought. See Richard R. Nelson, "U.S. International Competitiveness: Where Did It Come From and Where Did It Go?" *Research Policy* 19 (April 1990):117-132.

42. National Science Foundation, *International Science and Technology Update: 1988.*

43. U.S. Department of Commerce, Bureau of Economic Analysis.

44. For a more detailed examination of corporate time horizons and technology development, see National Academy of Engineering, *Time Horizons and Technology Investments* (Washington, D.C.: National Academy Press, 1992).

45. Precisely because of the slower projected future growth of the U.S. labor force, efforts to improve U.S. workers' skills cannot focus exclusively on primary and secondary education. Entrants to the work force will constitute a much smaller share of the labor force over the next 5 to 10 years.

46. U.S. Congress, Office of Technology Assessment, *Rebuilding the Foundations: State and Local Public Works Financing and Management* (Washington, D.C.: U.S. Government Printing Office, March 1990) 36, 40.

2

Government Support for Civilian Technology

This chapter examines several past and current federal programs to support private sector research, development, technology transfer, and adoption. It also summarizes the evidence on foreign governments' sponsorship of pre-commercial technology development. We begin with a discussion of the rationale for government support of pre-commercial R&D and technology development. The structure of postwar federal support for basic research is then outlined, as well as the history of federal sponsorship of civilian technology development.

Federal technology programs have a long history and a diverse nature (in both structure and outcomes). Based on this history, the factors that appear to contribute to success in government-industry cooperation in civilian technology developments are discussed. This chapter then reviews the strengths and weaknesses of current federal programs to stimulate technology development, as well as programs aimed at the adoption and transfer of new technologies.

An important part of federal investment in technology development, much of which is defense related, involves R&D performed at the federal laboratories and work sponsored by the Defense Advanced Research Projects Agency (DARPA). This chapter accordingly discusses the current and prospective roles of these organizations in a modified federal technology policy. It concludes by presenting a framework for strengthening the capacity of the United States to support private sector technology development and commercialization in “pre-commercial” areas. Pre-commercial R&D is a process that generates knowledge and technical information with a capability for application across a wide range of products and processes. It involves R&D before construction of the prototypes for commercial application but after indications of general commercial potential for the R&D work in progress.[1]

FEDERAL INVOLVEMENT IN RESEARCH AND TECHNOLOGY

For much of this century, the federal government has played an important role in the development of civilian, nonagricultural technology. In agriculture, federal and state programs for research and extension (support for technology adoption) date back to the nineteenth century.[2] Another source of federal support for civilian technology development has been an indirect one—federal funding of basic research.

A major federal role in support of basic research has long been viewed as appropriate. It is recognized that technological progress through innovation, of which basic research efforts are a central part, provides for increases in productivity and economic growth.[3] Government financing of research to support technological change stems, in part, from the recognition of the need to compensate for the ineffectiveness of private markets in this area. The economic returns on investments in basic research often lie far in the future. Moreover, the returns on investment in basic research are difficult for the investor to protect and capture with devices such as patents or copyrights. The returns to the investor from basic R&D activity are correspondingly low.

The returns to society as a whole, however, can be high, as numerous studies have shown.[4] The difficulties in capturing the returns from basic research investments give rise, therefore, to a form of “market failure” in which private returns to the would-be investor are lower than the returns to society as a whole. Without some form of public intervention, market institutions will lead to underinvestment in this type of research activity.[5]

Federal support for civilian technology development has been confined primarily to support for basic research. Nonetheless, in several areas, the federal government has assumed a more direct role in supporting technology development downstream from basic research. Risk and uncertainty are inherent in any development project and, by themselves do not justify funding of projects by the federal government. Nevertheless, investments in ventures beyond basic research have been justified on the grounds that private firms, in some instances, are not able to “appropriate” or capture sufficient benefits from projects that serve specific missions of federal agencies or the general welfare. Public funds support research and technology development in technologies deemed essential to agency missions; in recent de cades, this rationale has led to large investments in defense, transportation, and space technologies.[6] For historical and political reasons, federal and state funds have also supported a large research, technology development, and extension system in agriculture.

With several important exceptions, federal funding of civilian technology beyond the basic research stage is viewed as unjustified. This view of federal involvement in technology has held that public investments simply substitute for the investments that would be made by private firms in the absence of government incentives. Worse yet, it is feared that direct subsidies may distort private investment incentives, leading to the development of costly and commercially unsuccessful technology projects. (The federal Supersonic Transport program is frequently cited as an example of this type of problem.) In sum, because the returns from investments in civilian technology development can be captured by private firms, this theory suggests, there is no market failure, and public incentives to stimulate private activity are unnecessary.

Market failure, we believe, is not absent from the stages of technology development that lie “downstream” (i.e., closer to technology development and application) from basic research. Policies based on a framework that denies the existence of market failure in pre-commercial areas employ an unrealistic view of the innovation and technology development process. Basic research rarely yields results that can be translated swiftly and at low cost into commercially remunerative technologies. Moreover, the economic benefits of fundamental advances in R&D do not end at the basic research stage. Instead, investment incentives are often needed in pre-commercial research to improve theoretical understanding, and to test and explore potential technology applications and designs. In many cases, these activities include considerable “basic” research work. Therefore, technological innovation (after the invention of new product or process technologies) is characterized by high risks, high and rapidly increasing costs (indeed, for most technologies, the costs of development and application, as noted in Chapter 1, significantly exceed the costs of the basic research underpinning them), and great uncertainties.

Technology, as well as science, moves rapidly across international boundaries, and intellectual property protection does not completely prevent imitation, reverse engineering, or improvements of the basic technology. The returns from many investments in technology development, therefore, are often not easily appropriated by the investor. Moreover, changes in the global economic environment, including improved communications, rapid economic growth and strong technological capabilities overseas, and the importance of foreign trade and capital flows in the U.S. economy, may have further impaired the ability of U.S. firms to capture the returns from investments in technology development, as well as from basic research.

The argument that federal support should be confined to basic research also overlooks the possibility of market failure in the adoption of new technologies—an important area in which the United States needs to improve its performance, as noted in Chapter 1. The issue of nonappropriability, or the inability of firms to capture economic benefits of investment in basic research—long accepted as the rationale for public support—deals largely with a putative undersupply of that type of research. This view overlooks the fact that the transfer and utilization of new scientific or technological information generally involve significant appropriability problems for private firms. The organization of R&D capabilities in industry rests on the inability of firms to capture the returns of investment in technology transfer and adoption activities, as noted below. Public support for technology development, therefore, may legitimately include a role in supporting its utilization and diffusion, as well as the creation of technological knowledge.

In sum, an expanded federal role in supporting pre-commercial R&D and technology, as well as domestic technology adoption, is justified on the grounds that market mechanisms do not promote efficient levels of investment or performance in these areas. Moreover, to improve U.S. performance in technology commercialization and adoption, a better balance between support for basic research and investment in pre-commercial R&D and technology adoption is necessary.

Federal Support for Basic Research

Government involvement in the development of civilian technologies has a lengthy history and has assumed many forms. Many of the high-technology industries in which U.S. firms are now dominant or strong performers within the global economy benefitted from federal funding of basic research or from defense-related research, development, and procurement programs. Basic scientific research has played an important role in advances in telecommunications, environmental sciences, and many other areas. In biotechnology, the growth of start-up companies and advanced applications in genetic engineering have been made possible in part through federal funding of research at universities and medical institutes. Government funding of scientific research has also contributed both to the physical capital necessary to support the nation's science and technology base—construction of scientific and engineering facilities, and equipment purchases—and to the education and training of the U.S. work force.

The role of the federal government has also included the education of scientific, engineering, and academic personnel employed in government, industry, and universities. As federal funding of research has increased, the number of scientists and engineers has also risen (more than 60 percent from 1977 to 1987 and 8 percent per year in the 1980s).[7] Sponsorship of academic fellowships and grants creates incentives for postsecondary students to enter science and engineering fields. The government currently supports, for example, more than 49,000 fellowships, traineeships, and research assistantships for graduate education in science and engineering.[8]

Federal support for basic scientific research remains important to the national welfare. It must be recognized, however, that an exclusive federal focus on basic research investment in order to sustain U.S. advantages in technology is no longer sufficient. Scientific research is increasingly an international public good. The growth of transnational corporate alliances, the increase in direct investment in the United States and abroad by foreign-based firms, the participation of scientists and engineers from one country in the laboratories of other countries (especially those of the United States), the emergence of new centers of technical and industrial prowess, and the swift dissemination of technological knowledge through advances in information processing and transportation have combined to diffuse new research findings rapidly around the globe.[9] The pace as well as the amount of technology transferred through these transnational mechanisms is accelerating.[10]

The worldwide diffusion of new technical knowledge makes it difficult for U.S. firms to appropriate the benefits of research conducted in other countries. During the 1950s and 1960s the United States was able to translate innovations produced through this complex research system into marketable products with little challenge from commercial competitors. Today, not only are foreign firms more capable of absorbing the output of the U.S. scientific and engineering enterprise, they also challenge U.S. companies by quickly incorporating research results into commercializable products and processes, as well as rapidly adopting new technologies.

The openness and accessibility of the global research system and the free flow of information and ideas have contributed to this development. One response to the globalization of basic research is to maintain current federal research investment priorities and attempt to reduce transfer of the results of such research to foreign firms. This is likely to be both ineffective and, ultimately, profoundly counterproductive. The economic benefits and payoffs to U.S. industry and citizens from an exclusive government focus on federal investment in basic research may, we believe, have been reduced in recent years. The appropriate response, however, is not to attempt to restrict foreign access to U.S. basic research. Such an action would harm the global scientific enterprise, as well as reduce the effectiveness of our basic research system and, ultimately, impair the competitiveness of U.S. firms.

As a nation, it is likely that the United States has less to gain and more to lose by restricting foreign access to its research system. This is true today more than at any other time in the postwar period. Moreover, in some cases, the United States (including federal laboratories and federally sponsored R&D projects) is less open to the participation of "foreign" firms than other industrialized nations and could be subject to retaliation in the future.[11] The United States should seek to promote access to publicly funded research projects, both here and overseas.

Although post-war U.S. policy has emphasized funding of basic research, the government has acted to aid U.S. firms in commercial technology development and the adoption of new technologies. The next section outlines several examples of federal involvement in private sector activities beyond funding of basic research. As we show, the U.S. government clearly has the capacity to facilitate the commercialization and adoption of new technologies in important high-technology sectors. This success, we believe, indicates the capability of government to act in a manner consistent with support for downstream investments in pre-commercial R&D with a high rate of social return. It also shows federal capability to aid U.S. firms in technology adoption.

Government Support Beyond Basic Research

In agriculture, public health, computers, and civilian aeronautics technologies, among other fields, investments by federal agencies—the Department of Agriculture, National Institutes of Health, Department of Defense (DOD), and National Advisory Committee for Aeronautics (NACA)—contributed to technology commercialization and the adoption of new technology in private firms. Indeed, in aircraft, high-performance computers, and agriculture, the federal government had a direct role in the creation of industries that today dominate world commerce and generate export surpluses for the United States. Other less successful federal efforts, in areas such as synthetic fuels, provide insights into how to improve the organization and structure of publicly supported programs in civilian technology. The following sections detail lessons learned from past federal programs that can shape future policies and programs.

Agriculture

The land resources of the United States, its large farm population, and innovations—such as seed drills, reapers, and steel plows—contributed to the success of the nation's agricultural sector, particularly in international markets in the late 1800s. Progress during the 1900s, however, was shaped by a series of legislative initiatives that provided government funds for R&D and agricultural extension services.[12] Many studies of agricultural productivity growth and federal investment have documented a high rate of return from these types of investments in pre-commercial agricultural research and technology.[13]

One important legislative development during this period was the 1887 Hatch Act, which provided funds to the states for agricultural "experiment stations."[14] In conjunction with agricultural colleges, the stations formed a system that "extended" agricultural knowledge and research findings to the farmer. The 1906 Adams Act encouraged mission-oriented, basic research at the local level through increased funding of state experiment stations, with the stipulation that they use funds for "conducting original researches."[15] The 1914 Smith-Lever Act provided grants for such activities as farmers' institutes, demonstration farms, and vocational education.

The Department of Agriculture has placed much of its research locally in experiment stations managed by the states.[16] County-based agents were essential to dissemination of technology from the federal, regional, and extension laboratories to the local farmer.[17] This emphasis on government-sponsored technology extension is unique to agriculture (standing in sharp contrast to the lack of extension programs to support U.S. manufacturing). Agricultural research and extension programs are focused on servicing external "clients" (i.e., which reinforces the link between R&D and commercial markets).[18] Extension agents provide both technical information on advances in agricultural technology and assistance with business management.

Agricultural extension programs have been a useful, although costly, mechanism for upgrading the technological capabilities of farmers and promoting the diffusion and adoption of new technologies. The agricultural program provides several important lessons on federal involvement in civilian technology development and adoption. The most important of these include (1) the need for a wide diversity of specific projects and flexibility in extension management; (2) the value of a continuing focus on the application of findings and technology adoption that affect a wide range of private sector actors; (3) the importance of a long-term, stable source of funding; and (4) the benefits of wide access to projects among private sector participants.

Computers and Microelectronics

Federal R&D support was essential to the creation of the U.S. computer and semiconductor industries. The first computers were constructed in military research and development projects during World War II. In the 1950s and early 1960s, government military purchases of semiconductors, largely for use in missile guidance systems, aided the development of the U.S. semiconductor industry. Through R&D and procurement programs, federal assistance to private R&D projects helped to lower production costs through subsidization of manufacturing test and production facilities. In addition, the SAGE air defense program required development of innovations to coordinate multiple computers operating continuously. (Additional contribu tions of the Department of Defense to the computer industry are addressed below in “Government Support of Dual-Use Technology: DARPA.") In fact, between 1945 and 1955, all major computer technology projects in the United States were supported by government or military users, or both.[19]

Although IBM funded early development work in electronics and computers during the 1940s and 1950s, sales of these products to the federal government generated a significant amount of revenue for the company.[20] Direct government support for R&D work, special projects, and studies was received for defense-related purposes at IBM, including programs associated with the B-52 bomber and navigation system. In addition, from 1953 through 1955, 6 of the 18,701 computers (the company’s first-delivered computer) sold by IBM went to government agencies and laboratories. Other projects for the government, such as the SAGE and Stretch programs for the military, helped to advance the firm’s technological frontiers in commercial products, including the diffusion of transistor technology in IBM products.

Cray Research, Inc. developed supercomputers by working as a contractor for Los Alamos National Laboratory, which functioned as “the market” by defining specifications and evaluating the quality of machines installed at its facilities. At critical junctures, federal purchases of Cray supercomputers kept the company in business. In addition, extensive government investments in computer networks in the 1970s and early 1980s, reduced instruction set computing, and sophisticated graphics are now bearing fruit in commercial applications.

The federal government played an important, direct role in the commercial development of the computer industry. Clearly, much of the success of this involvement can be attributed to government procurement practices, which helped ensure a market for products supported through DOD and DARPA. Nevertheless, early federal support also included pre-commercial R&D and prototype development projects that assisted firms in moving beyond research into technology commercialization in civilian markets.

The Biomedical Industry

The growth of the U.S. biomedical industry—pharmaceuticals, medical equipment and devices, and more recently, biotechnology—was supported by government funding of medical research and the training of scientists and medical personnel by agencies such as the National Institutes of Health (NIH).[21] Collaborative projects in biomedicine established a precedent for the expansion of cooperative R&D programs in subsequent decades. The dominant role of NIH in funding U.S. biomedical R&D evolved through the agency’s wartime programs. Prior to World War II, as part of the Public Health Service, NIH helped develop treatments for then prevalent ailments such as malaria, tuberculosis, and venereal disease. The 1944 Public Health Service Act led to the establishment of new NIH research entities such as the National Heart Institute and the National Institute of Mental Health.[22] In 1946, the Office of Research Grants was founded and became the primary grant-making body for medical research in the postwar era. Along with grants initiated by individual medical researchers, which still constitute the bulk of NIH allotments, funds for the construction of medical facilities and graduate and postdoctoral training fellowships were also disbursed.[23]

Biotechnology

Today, the federal government, largely through NIH, the National Science Foundation, and the Department of Agriculture, spends approximately $3.5 billion a year on biotechnology-related R&D. The private sector invests another $2.5 billion. NIH employs 4,184 scientists and physicians, and in 1990 allotted $5.2 billion of its total budget of $7.6 billion for more than 24,000 research grants. NIH spent $1.7 billion on research in biotechnology fields, such as genetics and molecular biology, and process technology work, such as DNA cloning. Funding in the second category rose sharply from $0.2 billion in 1986 to $1.2 billion in 1990.[24] NIH laboratories test chemical compounds for use in biotechnology products and processes.[25] In addition to NIH support for biotechnology, $195 million per year is spent on the human genome project, which is administered by the Department of Energy (DOE) and the Department of Health and Human Services.[26]

Several lessons that are evident from close examination of government support for biology may be helpful in redirecting federal science and technology policy. First, current federal policy on biotechnology recognizes that collaboration between firms and universities is essential.[27] Cooperation between the private sector and government-supported universities often involves long-term agreements between individual firms and a university. Federal funding of research, particularly of university-industry collaborative projects, has helped support a strong, internationally competitive U.S. biotechnology industry.[28] NIH research has led to breakthroughs such as gene therapy, the development of a test for the presence of the human immunodeficiency virus (HIV), and the drug AZT (azidothymidine) for AIDS treatment. The U.S. leadership in biological science has translated into a strong national position in world markets for U.S. biotechnology products.[29]

Second, NIH is the leading provider of R&D and training to the biomedical industry. Although direct support is primarily for basic research, the close relationship to industry and the short time to product development have blurred the distinction between support for basic research and for pre-commercial R&D. NIH labs have built strong relationships to the health care industry and its management. The links between researchers and in dustrial users are an important element in the biomedical industry's success in transforming laboratory R&D into commercial applications.

Finally, NIH's historic tradition of decentralized peer review of research proposals has helped provide protection from political interference for the tens of thousands of research proposals examined each year by 139 review councils and panels. From the beginning, the Office of Research Grants emphasized the "integrity and independence of the research worker and his freedom from control, direction, regimentation and outside interference."[30] As in other fields, independence from political interference has fostered continuity in research and helped preserve the independence of scientific inquiry and projects.

The Civil Aircraft Industry

The U.S. government played a strategic role in the development of a civilian aircraft sector. A central focus of this involvement was funding of applied research and construction of aircraft prototypes. The government conducted most R&D in aviation prior to World War II, at which time the growth in military and private sector aviation reduced the governmental role in civilian R&D.

From its founding in 1915 to its absorption by the National Aeronautics and Space Administration (NASA) in 1958, the National Advisory Committee for Aeronautics was the predominant government body supporting civil aircraft R&D. NACA was formed during World War I, when biplanes were used for reconnaissance and dirigibles were used in bombing.[31] Beginning with work on a new wind tunnel at Langley, Virginia, NACA was responsible for a series of aeronautical innovations that helped foster the establishment of a U.S. aircraft industry. The development of an engine cowl reduced wind drag, research in aerodynamic efficiency assisted determination of optimal engine placement, and a new family of airfoils allowed engineers to test new shapes in wing design. Furthermore, by publishing technical documents on aviation engineering, NACA became recognized as a world-class authority on aeronautics. NACA appropriations through 1940 totaled $81 million (1972 dollars).[32] The number of NACA employees did not exceed 100 until 1925 and was less than 300 as late as 1935.[33] Experience with federal technology developments in this program shows that significant accomplishments in pre-commercial and applied R&D do not necessarily depend on large expenditures of funds for each research project.

Regulatory policies also had an impact on the development of the civil aviation industry. NACA-sponsored discussions on an industry-wide cross-licensing agreement led to the transfer of technology among companies. Under the accord, companies gave up exclusive patent rights that might have served to promote a single firm's technological dominance.

From 1938 to 1978, the Civil Aeronautics Board (CAB), strictly regulated airline fares and market entry by air carriers. These regulatory policies had the effect of constraining market efficiencies while spurring technological innovation, because airlines were forced to compete on the basis of technology as opposed to cost. After World War II, spin-offs from military R&D and transfers to the private sector from military-based research and procurement had a decisive effect on the commercial sector. Manufacturers such as Boeing and General Electric that worked in both the military and the civilian jet-aircraft and jet-engine markets were able to leverage the cost of production and technology development across both areas.

NACA's efforts in technology diffusion and encouraging the adoption of new technology through dissemination of technical documents were successful in spurring technological advances in the United States. NACA (and later NASA) also encouraged companies of comparable technical ability to share R&D findings in large joint projects.[34] In addition to support for R&D and the adoption of new, innovative technologies in the civil sector, NACA and NASA played a key role in support of the infrastructure underlying the commercial aviation industry.

There are several important lessons to be gained from the government's involvement in support of the commercial aircraft industry. First, NACA concentrated on areas of pre-commercial, applied R&D with broad application throughout the industry. Private companies then took the research results and specialized in technology commercialization. Program managers at NACA facilities were not involved in specific decisions on product applications. NACA generally limited its support to "generic, enabling technologies" from which current or future product design programs would benefit.

Second, NACA's research efforts were unstructured and minimized overlapping responsibilities, in contrast to many current federal programs. Research projects were initiated after informal approval from staff supervisors or NACA's executive committee.[35] The organization's relatively small size and single location contributed to close staff collaboration. NACA was also able to attract high-quality scientific and engineering talent. Staff was not restricted to narrow technical specialties, which promoted the wide transfer of technical information and expertise.

Synthetic Fuels

The government's attempt to develop a synthetic fuels industry in the late 1970s and early 1980s is a case study of unsuccessful federal involvement in technology development. In 1980, Congress established the Synthetic Fuels Corporation (SFC), a quasi-independent corporation, to develop large-scale projects in coal and shale liquefaction and gasification.[36] Most of the projects centered on basic and conceptual work that would contribute to demonstration programs in later stages, although funds were expended on several prototype and full-scale demonstration experiments.[37] Formed in response to the 1970s energy crisis, the SFC was intended to support projects that industry was unable to support because of technical, environmental, or financial uncertainties.[38] Federal loans, loan guarantees, price guarantees, and other financial incentives totaling $20 billion were authorized to spur industry action.[39] Although SFC was designed to continue operating until at least 1992, the collapse in energy prices, environmental concerns, lack of support from the Reagan administration, and administrative problems ended the synthetic fuels program in 1986.

The failure of the federal government's effort to create a synthetic fuels industry yields valuable lessons about the role of government in technology innovation. The synthetic fuels program was established without sufficient flexibility to meet changes in market conditions, such as the price of fuel. Public unwillingness to endure the environmental costs of some of the large-scale projects was an added complication. An emphasis on production targets reduced research and program flexibility.[40] Rapid turnover among SFC's high level officials slowed administrative actions. The synthetic fuels program did demonstrate, however, that large-scale synthetic energy projects could be built and operated within specified technical parameters.

Energy programs of that time were hindered by excessive political interference. Political influence on funding allocation decisions, selection of R&D projects, or the direction and conduct of scientific research is counterproductive and damaging to the success of federal technology efforts. Fuel-cell projects under the SFC, for example, were allotted to each of the 50 states, regardless of economic viability. Implementation of energy performance standards for buildings was held back by complex regulations.[41] The clean coal technology project was hampered by congressional involvement in technical design and operational management. Although programs such as the tertiary oil recovery initiative and the R&D program in photovoltaic cells attained some success, these technologies were not widely adopted. In the case of photovoltaic energy, the government programs of the 1970s concentrated on research, as opposed to advanced development, in an immature technology.[42]

Assessing Federal Support

Changes in the international and domestic economic and technological environments have made the federal role in technology more important today than in past decades. As we have shown, the government can invest productively in civilian technology beyond basic scientific research. Factors that contributed to successful intervention in the past provide general guidelines on how best to structure that involvement. The following summarizes some of the most important reasons why federal incentives to private sector technology efforts have been successful in the past.

1. *Close links between users of the technology and federally supported R&D projects*: As in the case of federal support of biotechnology through the NIH, close involvement of researchers and industry in the design of collaborative projects is important to the success of R&D efforts.
2. *Investments by government and industry in diffusion of new technologies* : The success of federal efforts in agriculture and civil aircraft development and the failure of synthetic fuels development projects suggest that government involvement in commercial technology should include an emphasis on support for technology adoption and diffusion. In some cases, such as CAB regulation and commercial aircraft, support for technology adoption may be indirect. Programs that attempt to ignore market signals, fail to provide incentives for adoption, or exclude the diffusion of technical knowledge and information are likely to be less successful in aiding commercialization efforts than those that include these characteristics.
3. *Stable program funding and long time horizons*: A stable source of funding, either untied to or confident of annual appropriations, is one important component of successful government programs in civilian technology. The political process includes a bias against investments in programs that require long payback periods. Funding for agricultural extension programs, NACA project funding, and NIH support for research in biotechnology leading to improvements in product and process technologies, indicate the importance of stable program funding. In contrast, many of the alternative energy programs of the 1970s were hampered by demands for rapid success in untested technology areas.
4. *Limited political interference in program operation*: Political decision making and interference in project operations damage the chances for successful investments in commercial technology. The synfuels program, and its problems associated with the location of demonstration projects and the interference of legislative objectives, played a role in reducing the potential effectiveness of the project.
5. *Government program managers' avoidance of detailed decisions about specific commercial applications of the technologies developed*: NACA's success in facilitating the development of civil aircraft technologies was due, in part, to the agency's lack of direct coordination of R&D agendas once commercial applications became evident. To a significant extent, problems in the synthetic fuels program of the late 1970s can be attributed to direct involvement of program managers in selection of specific technologies for further commercial development.
6. *Cost-sharing*: Much of the past success of federal support for pre-commercial R&D and technology development can be attributed to cost-

sharing between the government and industry. Joint R&D, to which industry committed financial resources, served to link projects closely to market signals and in-house R&D efforts. Direct subsidization of technology projects by the government has had far less success in facilitating commercial R&D efforts.

7. *Avoiding excessive technological risk in time-constrained programs* : Federal technology development programs must balance the risks of excessive technological conservatism against the risks associated with attempting to quickly develop and commercialize “blue-sky” technologies. Successful federal programs, such as agricultural research and commercial aircraft, have avoided excessive commitments to quick commercialization of immature technologies.

CURRENT GOVERNMENT PROGRAMS TO SUPPORT TECHNOLOGY DEVELOPMENT

In addition to the programs in civilian technology development outlined above, postwar science and technology policy has included a commitment to dual-use and military R&D and technology development programs. Although this report centers on civilian technology, programs to support the defense industrial base, particularly high-technology development for defense, cannot be disregarded in an assessment of the federal role in promoting commercial R&D and technology. More than 90 percent of federal R&D funds go to industrial firms for defense-related programs. This funding has important implications for civilian technology commercialization efforts.

In the 1950s and 1960s, funding of R&D for defense-related technologies produced important civilian technology spin-offs in areas such as computers, semiconductors, and commercial airframes and engines. More recently, however, defense-related R&D has proved less effective as a source of new commercial technologies. Indeed, the relationship between the civilian and military areas of so-called dual-use technologies has changed significantly. In many technologies (computer hardware and microelectronics are among the best-known examples), advances in military applications now depend on rapid incorporation of technological innovations and applications from commercial technologies. Moreover, the economic viability of many U.S. suppliers of defense technologies depends increasingly on their fortunes in civilian, rather than military, markets. In the view of the panel, this change has important implications for the operations and priorities of one of the most successful supporters of defense-related technology development: the Defense Advanced Research Projects Agency.

Government Support of Dual-Use Technology: DARPA

The Defense Advanced Research Projects Agency was established in 1958 after the Soviet Union's launch of Sputnik. DARPA's full-time staff of 132 manages a $1.[43] billion annual budget that supports research and development in high-risk, advanced technology with potential applications to military systems.43 One of the primary motives for establishing DARPA was to develop technologies to serve missions in which no single uniformed service was interested or missions that spanned the needs of several of the services. Moreover, DARPA was primarily concerned with the "early-stage" development of new technologies. Their incorporation into specific weapons systems was the responsibility of the uniformed services' research and technology development facilities.

DARPA-funded projects have developed many advances in military technology, including advanced materials able to withstand extreme conditions, such as carbon-carbon composites and complex ceramics, as well as absorbent and nonreflecting materials critical to stealth aircraft.[44] Most significantly perhaps, the agency has been involved in funding R&D in computers, data communications, and computer networks. DARPA facilitated advances in artificial intelligence and packet-switched computer networks. It has also contributed to the development of both parallel processing and reduced instruction set computation (RISC). These types of investment have had not only a significant impact on U.S. military technology but also substantial "spillover" effects in commercial sectors.[45]

Although DARPA's budget was reduced during the 1960s, primarily because of the transfer of space-related development projects to NASA, it has risen steadily since the 1970s.[46] The agency's budget increased from $235 million in 1977 to $579 million in 1981 and $1.294 billion in 1989. Along with the increase in funding, DARPA developed from a project-oriented agency into a technology-based organization. Most of DARPA's work is now concentrated in the Pentagon's research, technology, and advanced development programs, in contrast to full-scale weapons system engineering. DARPA funds $673 million in exploratory development, with $645 million devoted to advanced development. Approximately $91 million is spent on basic scientific research and $24 million is allocated for mission support.[47] The agency often sponsors prototype development projects, such as for the Strategic Defense Initiative and the National Aerospace Plane, prior to the time the projects are transferred to one of the military services.[48]

Overall, DARPA is an efficient organization that has minimized bureaucratic obstacles to program success. It has been able to attract talented scientists and engineers from outside government. An important reason for DARPA's successes is that the Defense Department serves as a test custom er for the technologies developed by the agency. Projects benefit from feedback of user needs generated by a strong customer-client relationship. The agency has functioned as a "technology broker" or venture capitalist within the Pentagon, monitoring and funding the early development of advanced technologies. DARPA does not carry out research in its own facilities but contracts work to industry, universities, and branches of the armed services. Organizationally, DARPA is separate from the military services of the Department of Defense. The director of DARPA is responsible to the director of Defense Research and Engineering and, through this line of reporting, to the Under Secretary for Acquisition in the Office of the Secretary of Defense. The administration and Congress have different views on the degree to which DARPA should support "emerging" technologies, such as high-resolution systems and advanced semiconductors. In November 1989, for example, Congress expanded DARPA's authority by permitting it to serve as a venture capital bank for defense manufacturers.[49] Programs in very high-speed integrated circuits (VHSIC), x-ray lithography, focal plane arrays, and the MIMIC program have also been moved to the agency. Moreover, public policy research groups have recently recommended that DARPA be given specific responsibility for transfer to industry of defense technologies having commercial relevance.[50] The administration, however, has been concerned about extending DARPA's involvement in dual-use areas, particularly in specific pre-commercial technology areas. The agency's current policies and programs suggest that it is shifting its focus away from support of dual-use R&D and pre-competitive commercialization projects to an exclusive concern with military technologies.

The appropriate role for DARPA in commercial and dual-use technology markets should be reevaluated. Leading-edge military technology developments are increasingly "spun on" from the private sector to the defense manufacturing base. This trend has been accompanied by growth in private R&D spending relative to defense R&D expenditures, for example, in microelectronics, integrated circuits, data processing, telecommunications, and software.[51] The civilian infrastructure and commercial technology base is now much larger than that in defense and is important to defense systems.

Therefore, the performance of U.S. military-related technology is challenged less by lack of innovation in defense sectors than by the performance of dual-use and commercial innovators in the private sector. Moreover, as the effectiveness of military-funded R&D and military procurement as sources of civilian applications declines, federal military agencies such as DARPA need to tailor programs to meet this new reality.

The panel recommends that DARPA's traditional role in dual-use technology be reaffirmed. The agency's mission explicitly includes support for dual-use R&D and technology development that extends beyond military and national

security needs alone. These dual-use programs should focus primarily on areas in information science and technology in which DARPA has had success in the past.

This is not to suggest that DARPA become involved in technology development focused exclusively on civilian applications. The long-term success of the agency and its mission, however, depend on positioning it to take advantage of critical dual-use technologies that can be spun on into military applications which requires DARPA to have some involvement in the support of civil technology development.

The agency's experience in high-risk, cutting-edge military technologies makes it relevant in supporting research in dual-use technologies with similar characteristics. DARPA's work has included investments in projects that have focused on pre-commercial technology—in electronics, data processing, networking, and materials, among other areas. These are the types of investments in dual-use technology that DARPA's portfolio should include. Apart from the research and initial development stages of technology formulation, DARPA has also succeeded in building prototypes of new systems before they are transferred to the service branches. In semiconductor manufacturing and laser-based telecommunications, among other areas, DARPA has helped develop technology that was successfully transferred to the civilian sector by private companies.[52]

DARPA has not been successful in executing all of its objectives. The increasing complexity of Pentagon procurement policies has inhibited the agency's success in some instances. In recent years, DARPA has been unable to prevent the attrition of many highly skilled personnel. Congressional oversight of the agency's budget has been associated with considerable fluctuation in appropriations, reducing the stability of DARPA funding. These problems suggest that any federal entity established to support civilian technology development would benefit from insulation from congressional or executive branch micro-management, and would function more effectively if it could be exempt from complex federal procurement and civil service personnel regulations.

In strengthening DARPA's role in dual-use technology, appropriate action should be taken to ensure adequate staff and financial resources devoted to these tasks.[53] There are various options for strengthening the agency's organizational effectiveness. The agency's current structure could be retained even as its budget is increased and hiring restrictions are eased. Retention of high-quality staff is essential; however, regulations and restrictions on financial disclosure and future employment hinder DARPA's ability to attract qualified personnel.[54] Links to other federal technology agencies should be improved to avoid duplication of R&D efforts across federal agencies. Technology transfer to private industry should be given greater emphasis. Most important, given the increasing overlap of military and civilian innovation, technology transfer among DARPA, other defense R&D organizations, and civilian agencies of the government should be a primary mission of the agency.[55]

The Small Business Innovation Research Program (SBIR)

The Small Business Administration administers an important program that supports civilian technology development: the Small Business Innovation Research (SBIR) program.[56] SBIR was established in 1982 to fund R&D at small and medium-sized firms and to stimulate the commercialization of new products and processes.[57] The program also provides small companies with managerial and technical advice as well as financial grants. The 11 federal agencies participating in the program set aside 1.25 percent of their research budgets each year to fund SBIR projects. Grants are awarded for R&D in three phases: (1) project feasibility, (2) development, and (3) commercialization. The SBIR program made 3,183 awards, valued at $460 million, in fiscal year (FY) 1990. Grants were concentrated in the biotechnology field, energy systems, and defense-related projects. This program has proved important in facilitating pre-commercial R&D in biotechnology, as well as providing a bridge across which companies can move from start-up to commercialization. We believe this program has significant merit.

Congress should consider legislation to increase the agency SBIR set-aside. The program should be expanded so that more companies can participate in it.

U.S. Commerce Department Programs: The National Institute of Standards and Technology (NIST) and the Advanced Technology Program (ATP)

The 1988 Omnibus Trade and Competitiveness Act established several new technology transfer and development programs under an office of Technology Administration in the Department of Commerce.[58] Under the act, the National Bureau of Standards was renamed the National Institute of Standards and Technology (NIST) and placed within the Technology Administration. NIST encourages the competitiveness of U.S. firms in such areas as manufacturing modernization, enhanced process technology, and R&D commercialization. NIST's total resources in FY 1992 amounted to $453 million.

NIST employs 3,000 scientists and engineers and is host to approximately 1,000 visiting researchers each year at its facilities in Gaithersburg, Maryland, and Boulder, Colorado.[59] The institute's in-house laboratories conduct basic and applied R&D in the physical sciences and engineering to develop technical standards, calibration techniques, quality assurance methods, and technology generation. NIST's traditional laboratory work is conducted through facilities that focus on eight areas: (1) electronics and electrical engineering, (2) manufacturing engineering, (3) chemical science and technology, (4) physics, (5) materials science and engineering, (6) building and fire research, (7) computer systems, and (8) computing and applied mathematics. These facilities are engaged both in cooperative R&D projects with industry and in work that supports NIST's role of supplying data and information on standards and testing to U.S. firms. In addition to these activities, since 1988 NIST has sponsored the Malcolm Baldrige Quality Award Program for the Department of Commerce. Annual awards are made in manufacturing, services, and small business categories.

NIST also manages the Advanced Technology Program (ATP), one of several programs mandated by the 1988 Trade Act. The ATP funds businesses, especially small and medium-sized firms, in the research and development of "generic," “pre-competitive” technologies, to stimulate “high-risk, high-potential" products, processes, and technologies.[60] Under the ATP, a projected total of $229 million in federal grants will be expended over a five year period.

At the center of the ATP program are grants to cooperative research projects between industry and independent research organizations, including universities. All participants in these ventures must be U.S. entities. To ensure private sector commitment to a project, participating organizations must contribute a minimum of 50 percent of the total program costs, with NIST providing financial support for up to five years. Trade secrets, intellectual property, and information on the operations of businesses participating in ATP are to be kept confidential. The government is entitled to a proportion of licensing fees and royalties resulting from ATP projects.[61] In addition to providing funds for cooperative R&D, the ATP will provide advisory services and will loan NIST equipment and facilities to support R&D ventures. The ATP is charged with coordinating its programs with other federal laboratories through cooperative research and development agreements.

In FY 1990, ATP awarded $9.2 million in grants. The budget authority for FY 1991 totaled $35.9 million, and for FY 1992 $47 million. The administration requested $67.9 million for the ATP in fiscal 1993. Most ATP grants made in FY 1990 were for process technologies, such as the production of flat panel displays and precision machine tools; five of the eleven awards were for joint ventures. A mix of consortia, large multinational U.S. firms, and many small and medium-sized companies were awarded grants during the first awards cycle. Most applicants in the first round of grants were firms in electronics or materials science.

It is premature to comment on the possible impact of ATP funding on technology development or on directions the program might take in the future. The panel has, however, considered the framework employed in the design of this initiative, as well as the first-year grant awards selection process.

NIST has established a promising selection process for the ATP program. Criteria for selecting grant recipients include not only the potential scientific and technical merits of each project, but also the possibilities for technology transfer and anticipated application of new technology in each industry sector. Applications are processed through a series of technical and business reviews. A board representing federal agency officials, charged with resolving differences of opinion among reviewers, serves an advisory function for ATP program officers. At present there is no structure in place to support evaluation of ATP's performance by independent experts. Any such evaluation should avoid demanding immediate, tangible results or "deliverables," lest an excessively short-term operating philosophy be imposed on the ATP. Nevertheless, we believe that some independent evaluation of the ATP is needed.

There are difficulties associated with conducting a business review prior to clear market signals of the potential for profit from these types of investments. The ATP review process does serve to bring expertise from the private sector into the evaluation of a proposal's commercial potential.[62] Like NIH grant programs, the ATP program is separate from NIST laboratory activities so as not to interfere with the agency's primary mission.

The ATP program has had a promising start. It is not possible, at this early stage, to determine the program's success; nor should congressional or executive branch policymakers expect to see immediate, dramatic results. The panel has concluded, however, that the ATP's budget in the past has been insufficient to have a significant impact on U.S. technology commercialization efforts. An evaluation of ATP by an independent panel of experts, on an ongoing basis, would permit periodic determination of the desirable size of the program.

Role of Federal Laboratories in Commercial Technology Development and Transfer

The federal laboratories are an important part of the national science and technology infrastructure.[63] There are approximately 700 federal laboratories, with an overall budget in FY 1991 of $20.9 billion.[64] The laboratories' potential for technology commercialization has, however, been over-estimated. Any discussion of the utility of R&D conducted at the federal laboratories must first consider the high proportion of total federal R&D

expenditures that the laboratories represent. Table 2–1 shows R&D funding for these facilities, including both intramural agency laboratories and federally funded research and development centers (FFRDCs).

Federal policy on technology transfer from the laboratories should also take into the account the fact that these facilities are diverse in character, quality, and objectives. It is misleading to characterize this diverse set of facilities as a federal laboratory "system." The laboratories include single-office facilities operated by a handful of people, as well as large organizations with thousands of researchers, such as the Brookhaven National Laboratory in New York. Most government laboratories, however, are relatively small, staffed by five to ten full-time equivalent research employees. Moreover, most of these facilities are self-contained and are located within a federal agency or university. Although a few laboratories engage in activity related to commercial technology development, the majority are mission-oriented organizations that focus on research far "upstream" from applied R&D of commercial relevance or on systems specialized for military purposes. The federal government also supports large scientific user facilities that, because of their size and expense, would be difficult for any single firm or university to construct. Some of these installations perform important services for industry and provide a foundation for the training of scientists and engineers.

The primary mission of the federal laboratories will continue to be the fulfillment of traditional, agency-specific R&D objectives outlined above.

TABLE 2–1 Selected Federal Laboratory Obligated Expenditures, by Department, for FY 1991 (billion dollars)

Department/Agency	Total	Intramural	FFRDCs
Defense	10.212	8.988	1.224
Energy	4.443	0.427	4.016
National Aeronautics and Space Administration	3.278	2.573	0.705
Health and Human Services	1.940	1.879	0.061
National Institutes of Health	1.463	1.402	0.061
Agriculture	0.777	0.776	0.005
Commerce	0.350	0.349	0.001
Interior	0.469	0.435	0.029
National Science Foundation	0.299	0.187	0.112
Total	23.231	17.016	6.214

SOURCE: Calculated from data in National Science Foundation, *Federal Funds for R&D: Fiscal Years 1989, 1990, 1991*, 1991, Table C-9.

The ability of most federal laboratories to benefit the private sector is limited by this mission orientation. Only a few of the several hundred federal laboratories should be expected to support private sector technology commercialization efforts. This view contrasts with the perceived need for a larger role in technology transfer that has driven congressional and executive branch expectations and policies regarding the laboratories' role in supporting private R&D and commercialization goals.

The work with the most potential to contribute to commercially relevant civilian R&D is performed at the government-owned, contractor-operated laboratories (GOCOs), administered by nonfederal organizations such as universities or private firms. Government-owned and government-operated (GOGO) laboratories are, as the term suggests, administered by the federal government and staffed by government employees. Most of these laboratories do not have significant potential to contribute to civilian technology development.

GOGO laboratories are hindered in their efforts to support civil technology development in at least three important ways. First, GOGO laboratories are subject to civil service guidelines that impede their flexibility to hire staff, or to bring private sector scientists and engineers into their facilities. Second, federal regulations on procurement are obstacles to building effective links to the private sector. Finally, the implementation of broad programs and policies is dictated directly from agency headquarters to GOGO laboratories.

Contractor-operated laboratories are generally better suited for technology transfer and commercialization than those operated by the government directly. GOCOs have more of the operational flexibility necessary to forge closer links with customers in the private sector. Increasingly, participation in commercially oriented ventures is an explicit part of the mission of these laboratories. In addition, unlike government-operated laboratories, GOCOs are not burdened by civil service rules that inhibit flexibility in personnel recruitment and practice. The technical expertise housed in GOCO laboratories is, therefore, generally higher than that found in other types of facilities. Finally, administrative obstacles (including the difficulty of hiring laboratory personnel) are fewer in GOCO facilities. This is true despite an unfortunate tendency in federal agencies, in some cases urged by Congress, to apply in-house rules and procedures to GOCOs.

Traditional Missions in a Time of Change

The missions and funding of federal laboratories largely reflect the national priorities that existed as the national R&D infrastructure took shape after World War II. Most federal R&D resources have been directed to national defense purposes or, as is the case with the Department of Energy, to the development of nuclear weapons, reactors, and high-energy particle physics, for example. National needs, however, have changed.

Reflective of postwar science and technology policy, the largest proportion of federal laboratory spending continues to be directed to defense-related R&D. The Defense Department's share of total federal laboratory spending in FY 1991 was $10.2 billion, or 49 percent. The Department of Energy's share is $4.4 billion, or 21 percent. About half of DOE's laboratory expenditures are for military-related R&D; much of the remainder is for basic energy research (nuclear and elementary particles). The ratio of DOE funding for defense and basic energy research, in contrast to applied energy research, is approximately 5:1. Most Department of Energy laboratories and the FFRDCs are GOCO facilities. The latter perform much of the commercially promising work of the laboratories.

The Department of Defense funds both GOGOs and GOCOs. Most of the department's GOGOs do not have the potential to support technology transfer to the private sector. The highly specialized nature of the laboratories' defense-related R&D work is, for the most part, not suitable for civilian technology commercialization efforts.[65] In addition, DOD laboratories' restrictions on procurement and their inability, in many cases, to rapidly apply technology to systems and end products lessen the prospect that significant progress will be made in the department's commercialization efforts.[66] The DOD Defense Advanced Research Projects Agency, however, has a number of dual-use R&D programs in areas such as semiconductors and high-temperature superconductivity.

NASA labs accounted for $3.3 billion of federal laboratory spending in FY 1991. NASA's seven major research facilities focus on engineering development for space flight and space science. The Kennedy, Johnson, Marshall, and Stennis Space Flight Centers, and part of the Lewis Research Center, concentrate on manned space flight. The Jet Propulsion Laboratory (a GOCO) at the California Institute of Technology and the Goddard Space Flight Center are dedicated to space science. The Department of Agriculture spends $0.8 billion annually on laboratory programs, much of it through the Agricultural Research Service.[67]

Out of a total budget of $7.6 billion, NIH allots $5.2 billion a year to 24,900 research and training grants.[68] In 1991, NIH devoted about $1.5 billion to activities in the federal laboratories. Much NIH-sponsored biomedical research works its way into commercial applications in the biomedical, pharmaceutical, and biotechnology industries.

Recent Efforts to Promote Transfer and Commercialization

A series of legislative and executive branch initiatives during the 1980s attempted to encourage technology transfer from the federal laboratories.

The Patent and Trademark Amendments (Bayh-Dole) Act permitted federal agencies to grant licenses to small businesses and nonprofit institutions, including universities, for inventions made at government-and contractor-operated laboratories.[69] The Stevenson-Wydler Act, passed the same year, formally made technology transfer from the laboratories to private industry a policy of the federal government.[70] The legislation mandated that 0.5 percent of each laboratory's budget be allocated for technology transfer and established budgets for information offices on laboratory products and services—known as Offices of Research and Technology Applications—at every government-operated laboratory.[71] The 1984 National Cooperative Research Act limited potential application of antitrust laws for cooperative projects to encourage companies to collaborate in R&D.[72]

In 1986, the Federal Technology Transfer Act authorized the establishment of cooperative research and development agreements (CRADAs) between government-operated laboratories and industry.[73] A CRADA is an agreement under which a private organization provides personnel, equipment, or financing for specified R&D activity that complements the laboratory's mission. CRADAs are contractual agreements that include provisions for sharing intellectual property rights on inventions arising from them. (Separately, NASA has continued to enter into long-standing collaborative arrangements under the pre-existing authority of the 1958 Space Act.[74]) The Technology Transfer Act also established the Federal Laboratory Consortium to provide an interagency framework for technology dissemination.[75]

Executive Order 12591, issued in 1987, attempted to encourage the use of CRADAs by directing agencies to delegate authority for entering into these agreements to the laboratory and by issuing guidelines for the granting of intellectual property rights under such agreements.[76] More recently, the 1989 National Competitiveness Technology Transfer Act extended authority for entering into CRADAs to contractor-operated government laboratories.

Examples of Technology Transfer from the Federal Laboratories

Some examples of government-industry technology transfer have proved of wide benefit to private industry. Most of these incorporated the criteria for successful transfer discussed in Chapter 1. In the biomedical sciences, the close and long-standing ties of NIH laboratories to the medical and health care sectors have helped establish the commercial biotechnology industry. NASA work on R&D in remote sensing, earth-orbiting satellites, and characterization of mechanical properties of high-strength metal alloys, among other programs, has also had some modest impact on the civilian technology base.

Past experience with the NIH model of technology transfer, an outgrowth of R&D funding and collaborative work with the pharmaceutical and biotechnology industries, demonstrates that people from government and industry can work together successfully. Many of these joint projects have moved research results out of federal laboratories and into the marketplace. One important reason for this success has been the high degree of interaction between researchers in separate organizations in the biomedical field. The critical interface necessary for successful transfer and adoption of the technology involved is people-to-people contact.

The Department of Energy has the most extensive program in technology transfer to the commercial sector. The agency's multidisciplinary, contractor-operated laboratories are widely considered to be among the most promising federal facilities for technology commercialization. There are nine multiprogram laboratories: Argonne, Brookhaven, Lawrence Berkeley, Oak Ridge, and Pacific Northwest emphasize energy R&D; Lawrence Livermore, Los Alamos, Sandia, and Idaho Engineering are weapons labs. There are also smaller laboratories noted for their work in energy research and applications, including the Solar Energy Research Institute (SERI), the department's main laboratory for basic and applied R&D in solar and renewable energies. SERI's R&D programs include close interaction with the private sector. The multidisciplinary nature of some DOE laboratories involves research and development in fields such as electronics and advanced materials. These are areas that rely increasingly on advances in crosscutting technologies. As noted earlier, almost all DOE laboratories are GOCOs: government-owned facilities that are operated by contracting firms and universities or other nonprofit institutions.

Potential Contributions of Federal Laboratories to Private Sector Technology Goals

Over the past decade, Congress and the executive branch have attempted to make civilian technology development an explicit mission of the federal laboratories. Yet, as measured by the number of patents or the amount of royalties resulting from laboratory transfer activities, this mission has not been fulfilled. In fact, few federal inventions are transferred out of these laboratories. A congressional committee investigating progress in meeting these goals found technology transfer efforts to be "under-staffed, under-directed, and only marginally focused."[77] These problems may not be as important as the key requirement for effective transfer—a close customer relationship. They are, however, inhibiting laboratory-industry collaboration.

One indication of the lack of success in forging close relationships is the small output of technologies licensed to the private sector from federal ly sponsored R&D performed at the laboratories. For FY 1989, 297 research-oriented federal laboratories surveyed by the General Accounting Office produced only $6.3 million in royalties and 676 patents. Approximately 31 percent of these laboratories had not received guidance for implementing the Federal Technology Transfer Act of 1986. “The major provisions [of the Act]," the agency concluded, “still have not been fully implemented."[78]

TABLE 2–2 Summary of Patents, Licenses, and Royalties, Fiscal Year 1989

Department/ Agency	Patents Pending	Patents Issued	Exclusive Licenses	Nonexclusive Licenses	Total Royalties ($)
Commerce	20	2	0	7	0
Defense	1,142	289	17	15	4,570,472
Energy	548	211	24	30	888,800
Interior	14	8	1	0	13,900
Transportation	0	0	0	0	0
Environmental Protection Agency	6	1	1	0	0
Health and Human Services	139	22	1	0	814,232
National Aeronautics and Space Administration	253	98	30	19	35,100
Agriculture	99	44	10	8	1,500
Veterans Administration	12	1	1	3	0
Total	2,233	679	85	82	6,324,004
Laboratories Responding	241	247	247	242	272

SOURCE: General Accounting Office, Program Evaluation and Methodology Division, *Diffusing Innovations: Implementing the Technology Transfer Act of 1986*, 1991.

Table 2–2 provides an overview of one measure of federal output in technology transfer. The amount of technology transferred from the laboratories is strikingly meager, particularly when compared to the $23 billion per year in total federal laboratory R&D expenditures. There are other measures of output that indicate limited progress in linking federal laboratories to provide sector R&D—at least in the initial stages of the development process. Table 2–3 shows the total number of CRADAs that federal laboratories have entered into since enactment of the 1986 Technology Transfer Act. The number of contracts signed between laboratories and firms does not indicate the utility of these agreements to meet specific technology objectives. It does show some limited progress in linking a few federal agency laboratories to industry through CRADAs.

TABLE 2–3 Cooperative Research and Development Agreements (CRADAs) in Selected Federal Agencies

Department/Agency	Number of Scientists	Number of CRADAs	CRADAs per Thousand Scientists
Laboratories			
Army	25,000	104	4
Navy	10,000	40	4
Air Force	23,000	33	1.4
Agriculture	2,300	206	90
Commerce (includes NIST)	3,900	145	37
Energy	35,000	38	1.1
Environmental Protection Agency	850	35	41
Health and Human Services (includes NIH)	6,300	155	24.6
Interior	6,900	10	1.4
Transportation	500	7	14
Veterans Administration	2,500	15	6

SOURCE: Calculated from data in National Institute of Standards and Technology, *Cooperative Technology RD&D Report*, September 1991, Vol. 1, No. 2, pp. 10–15.

The primary difficulty with technology transfer from the federal laboratories to industry is that there is little organized, close collaboration between these various groups outside the defense area. In technology development programs for national defense, the government is the customer. The government writes the requirements and specifications and then receives the manufactured products and weapons systems for which it contracts. In civilian technology programs, however, the government is not the customer. It does not have the insight and detailed, critical knowledge of who the customers are.

Moreover, technology transfer from federal laboratories to civilian industry presents a set of problems with which the United States has had only limited experience. There are a few examples of successful collaboration, primarily in transferring basic results to industry and sponsorship of external R&D. Much of the R&D performed at the federal laboratories is either directly related to defense R&D, centered on basic research tied to mission objectives of federal agencies, or not of the nature that most private firms find useful, given their timetables for commercial market objectives. As noted in Chapter 1, the process of technology development in many industries requires continual modifications and refinements of manufacturing products and processes that cannot be adapted to the laboratories' R&D work.

Current models of the relationship between technology and research rely on timetables for technology transfer that are too long and are impractical for the majority of manufacturing product and process development work. They assume an intellectual hierarchy with pure research as the prime source of new ideas. This assumption, we believe, is incorrect. The goal for policymakers should be to replace both the linear technology transfer and the passive diffusion approaches with a more efficient, more effective, and more rapid method of creating innovative technologies and products.

Over the past decade, most of the technology transfer effort has centered on removing barriers at the federal agency level. Yet the federal government should recognize that improvements will not result from a simple, mechanistic attempt to apply a "supermarket" approach to the laboratories' transfer activities. There is no concrete evidence to indicate any significant demand for commercially relevant federal laboratory technology in U.S. industry. Nor would the potential for this federally generated technology result in a dramatic increase in technology transfer if the laboratories simply provided easier access to their technology. The limited examples of instances in which technology has been of use to industry are characterized by a dynamic that has focused on a "market pull" model. In these instances, innovations developed by research facilities are incorporated over time into commercial products. This requires not only a substantial amount of time and resources devoted to a project at the laboratory level, but also large expenditures of resources by participating firms. Most companies, especially small and medium-sized firms, lack the requisite in-house expertise, R&D facilities, and funds to work effectively with the laboratories on commercially relevant technology.

In sum, it should be recognized that most government laboratory R&D is not relevant to industrial technology commercialization activities. In fact, the laboratories are both geographically and organizationally separate from their technology sources and potential collaborators in the private sector. Strong "cultural differences," reflecting attitudes toward scheduling, quality, profits, customers, and other factors, differentiate the federal laboratories from external organizations.[79] Even those few federal laboratories that perform R&D in civilian technology are neither regular customers for goods produced by private sector manufacturers nor their suppliers. They therefore lack critical knowledge of industry that is an integral part of any customer-client relationship in the commercial sector. Moreover, the mission orientation, focus on basic research, and in many cases, national security-related restrictions on outflows of technology inhibit technology transfer potential.

This is not to say that in specific circumstances and under special conditions, benefits cannot or should not be extracted from the laboratories for the civilian sector. Certain laboratories, such as some of the Department of Energy's multidisciplinary GOCO facilities, have greater potential to transfer commercially relevant technology than others. Some federal facilities, specializing in areas such as high-performance computing and electronics, energy development, advanced materials, space flight, and biomedical research, have much greater potential for civilian applications than others.

The most successful technology transfer and commercialization projects at the federal laboratories have been characterized by an effort to attract the active participation of industry, including greater protection for patent rights and solicitation of management advice on project design.[80] For example, in 1988 three high-temperature superconductivity pilot centers were established in the DOE laboratories at Los Alamos, Oak Ridge, and Argonne. Designed to involve industry from the start of initial research through commercialization, the pilot centers engage in application-oriented research that businesses (some 40 to date) specifically request.[81] The pilot centers work under contract with industry and provide significant intellectual property protection. Another innovator in this area has been Oak Ridge National Laboratory, which has an advisory council of business executives who offer recommendations for laboratory programs.[82] A third example of a promising technology transfer program is the ARCH Development Corporation established by Argonne National Laboratory in conjunction with its operating agent, the University of Chicago. ARCH has licensed more than 30 inventions by Argonne scientists, who receive 25 percent of gross sales income. The corporation also has formed a venture capital fund and draws upon business school expertise at the University of Chicago to analyze the commercial potential of proposals.[83]

As noted below, however, the extent of technology transferred through these programs is small, especially when compared to the size of affected industries. It is important to note again that the potential for technology transfer will differ markedly from laboratory to laboratory. Perhaps most importantly, the channels for the transfer and diffusion of commercially relevant technologies will differ, depending on each laboratory under consideration.

Guidelines for Improving Technology Transfer

Improving U.S. performance in technology commercialization requires a reorientation of federal R&D priorities. This is particularly true in regard to the allocation of resources at federal laboratories to meet technology transfer goals. Moreover, the basis for past legislative initiatives to spur technology commercialization in the federal laboratories appears to have been the conviction that a great wealth of commercially useful knowledge and know-how exists across the labs. We believe that this view is flawed. The resulting conclusion that technology transfer should be a priority mission for *all* federal laboratories has led to the imposition of an inappropriate standardized policy and set of regulations for technology transfer. This policy framework is not suited to the diverse set of R&D facilities represented by the laboratories.

Because only a few laboratories have the potential to contribute to private sector commercialization efforts, progress in strengthening the transfer process is ill served by agency-wide administrative decrees or by legislative mandates that require all federal laboratories to include technology transfer goals in their objectives. Furthermore, an increased role for the laboratories in private firms' commercialization efforts must not lead to a situation in which technology transfer overtakes traditional missions in serving agency-specific needs. Traditional missions of continuing relevance should continue to constitute the core functions of the federal laboratories. CRADAs, although useful mechanisms in certain laboratories, especially to establish the basis for sharing of intellectual property rights, promise few benefits in laboratories where linkages to the private sector are weak.[84] We believe, therefore, that laboratories with differing capabilities for technology transfer should be treated in a manner that reflects their varied potential. Efforts directed at strengthening technology transfer and meeting private sector commercialization needs must be aimed at a specific subset of the total federal laboratory establishment—those laboratories that possess the characteristics outlined earlier in this section.

The panel recommends that agencies whose activities could be closely linked to commercially relevant R&D, select one laboratory to focus on commercial technology development and transfer. These laboratories should serve as demonstration facilities, where efforts to transfer commercial technology have priority. The mission of these (few) laboratories should be changed explicitly to include civilian technology development and transfer. Laboratories with this new mandate must be able to conduct R&D programs consistent with a market-oriented framework and must have concrete ties to industrial partners.

The facilities referenced above are those, as identified by each agency, with the most potential for forming close links to commercial markets and with a high degree of current R&D work having potential commercial application. As the Office of Science and Technology Policy stated in a recent report, "the Federal Government has a relatively poor track record where it has invested in civilian technology without close involvement at the outset from potential users."[85] Furthermore, the federal government's national laboratories have been successful in fulfilling traditional missions such as weapons development partly because the government itself has played the role of a true customer, that is, by specifying "product requirements" and evaluating the quality of its "deliverables." The design, implementation, and review of projects undertaken at these selected laboratories should involve the direct participation of private sector advisory groups.

The Department of Energy has recently moved to make technology transfer one of the agency's three primary missions (in addition to weapons development and energy research). It is noteworthy that consensus on the design and implementation of collaborative agreements with industry has been reached through extensive consultation between industry and agency personnel.

In many cases, laboratory personnel have been reluctant to work on civilian technology development and applications projects because of the lack of adequate funding for these projects. Overall annual budgets at some of the laboratories have been reduced as federal defense spending declines. As laboratories face increasing budgetary constraints, already limited resources for technology transfer become even more scarce.

If civilian technology work is to succeed, therefore, significant human, financial, and equipment resources will have to be allocated to meet specific technology transfer goals. In the case of federal financial support, as in any research and development program, such assistance will generate greater benefits when funding is allocated for multiyear programs. In addition, to ensure that resources are allocated specifically for technology transfer functions, funding devoted to technology commercialization should be earmarked for such purposes through line item appropriations by Congress.

The removal of regulations that discourage private sector application of laboratory technology would also assist technology transfer. Moreover, laboratory equipment cannot be expected to contribute to civilian technology development if it is designed explicitly for noncivilian applications. Thus, further progress at laboratories selected for transfer missions will require widespread changes in operational rules, as well as redesign of these facilities. The conversion of some government-operated labs to GOCOs is a potentially useful option. To convert all government labs to GOCOs, however, would be exceedingly difficult, requiring expenditures of federal resources in excess of potential gains.

Because of the need for additional resources for commercialization efforts, the funding constraints under which the laboratories operate, and the shift in national priorities from military to civilian challenges, it would appear appropriate to close some federal laboratories and redirect resources in other facilities. The closing of selected facilities and the reallocation of resources from these facilities could provide sources of funding for new institutional approaches to technology transfer within and beyond the laboratory structure. (For institutional approaches outside the laboratory structure, see Chapter 3.) GOGO laboratories with outdated missions, or those that do not continue to serve mission agency needs, would be candidates for closure. Reforms to encourage technology commercialization must not jeopardize capabilities vital to national security needs.

Effective technology transfer, as noted previously, depends on the interaction of people from the laboratories and other organizations. New collaborative procedures should be formulated, and successful ones encouraged, to locate laboratory personnel at collaborating firms or universities and to draw the personnel of external organizations into collaborative work at federal facilities.

An essential feature of successful technology transfer is the participation of nongovernmental users in collaborative projects. Some federal programs have not been structured with this important characteristic. A survey of federal laboratories with the potential for technology transfer and "significant" R&D budgets found that 31 percent still lacked official guidance for implementing the 1986 Technology Transfer Act. One hundred and fifty-six laboratory directors were found to lack the authority to participate in CRADAs.[86] These data suggest that a larger role for industrial affiliates in strategic planning, project selection, and program operation of the laboratories is necessary.

Finally, industry should be provided with sufficient incentives to commercialize federal technology. It should be clear that the primary responsibility for building relationships between federal laboratories and industry rests with the laboratories. Streamlined procedures and simplified contracts for laboratory-industry interaction should be encouraged to reduce the amount of procedural barriers to cooperation. In addition, creative mechanisms for the protection of intellectual property resulting from cooperative ventures should be developed. Manufacturers have been reluctant to commercialize federal laboratory technology, in some instances, due to inadequate mechanisms to protect intellectual property rights.

COOPERATION IN RESEARCH AND DEVELOPMENT

A central question facing Congress concerns the strengths and limitations of cooperative R&D. This section briefly examines the potential benefits and areas of application of cooperative R&D, with a particular focus on examples of Japanese and European ventures. Tentative lessons from several of those experiments are discussed. Although it has not generated extensive results or lessons, recent U.S. experience with collaborative R&D is also outlined in this section.

The U.S. experience with cooperative industrial R&D programs involving multiple firms extends to the early post-World War II era.[87] Research ventures in large, military-related projects—supercomputers, aircraft development, and semiconductors—joined U.S. businesses in efforts to develop technologies for defense purposes. Most collaborative ventures without direct federal involvement prior to the 1970s included arrangements among companies in vertical industry sectors—automobile manufacturers and petrochemical firms collaborating to develop ceramics for use in auto bodies, for example. In other cases, horizontal associations of firms within a single industry formed cooperative research organizations. Many of these promoted technology adoption and the diffusion of information and technology within member firms and were not focused on basic research. Three well-known examples, involving firms that by and large are not direct competitors, are the Electric Power Research Institute (formed in 1973), Bell Communications Research (Bellcore, founded in 1984), and the Gas Research Institute (founded in 1976).

A number of private research consortia have been organized during the past decade in other sectors.[88] These arrangements involve cooperation between companies without direct government encouragement or financial incentives. For example, the Semiconductor Research Corporation, formed in 1983, sponsors research at U.S. universities and includes 33 industrial members, such as AT&T, DuPont, and Eastman Kodak. The Microelectronics and Computer Technology Corporation operates in-house R&D facilities and sponsors research on semiconductors and advanced computer technology outside the consortium. The Software Productivity Consortium focuses on computer software for military applications. These are all cooperative efforts that join competitors in similar product markets. Although most recent assessments of cooperative R&D have focused on programs in high-technology industries, collaborative ventures have been established in “mature” industry sectors, as well. The Textile/Clothing Technology Corporation and National Apparel Technology Center, for example, were created to improve the technological capabilities of U.S. textile manufacturers.

Congress has attempted to promote the formation of these alliances through the elimination of perceived barriers to collective R&D. This was the purpose of the National Cooperative Research Act (NCRA) of 1984, which eliminated the threat of treble damages in private antitrust suits for cooperative ventures that register with the Justice Department under NCRA. (Even for ventures that file with the department, it may determine that projects have changed in a substantial manner, and thus protection is no longer warranted.) The law also states that cooperative R&D ventures should not automatically be judged anti-competitive but rather should be evaluated, if challenged in court, on a rule-of-reason basis.[89]

The U.S. government also has directly supported research collaboration through the establishment of mixed public/private ventures aimed at developing advanced manufacturing technologies, such as the Semiconductor Manufacturing Technology Research Corporation (SEMATECH) and the National Center for Manufacturing Sciences (NCMS).

SEMATECH is a Texas-based consortium of 14 U.S. semiconductor manufacturers and the Department of Defense. The goal of SEMATECH is to provide U.S. manufacturers with the capability to achieve world leadership in semiconductor manufacturing technology by 1993.[90] Since 1988 the Defense Department has provided half of SEMATECH's $200 million operating budget. Congress has appropriated $100 million per year for five years for SEMATECH. Responsibility at DOD for oversight of SEMATECH was delegated to DARPA in 1988. Membership in SEMATECH is restricted to U.S. companies.

SEMATECH employs approximately 550 people. Half of the full-time staff are scientists and engineers assigned from member companies' R&D facilities. The consortium initially constructed a wafer fabrication facility at its headquarters for the demonstration of advanced integrated circuit production equipment, processes, and methods. This facility was used for the production of both Dynamic Random Access Memory (DRAM) and Static Random Access Memory (SRAM) chips. SEMATECH has also concentrated on the development of advanced materials for semiconductor processing. Since 1990, SEMATECH has devoted a significant share of its total resources to R&D contracts with producers of semiconductor manufacturing equipment and materials, and with universities. It is also helping build relationships between U.S. semiconductor manufacturing equipment producers and manufacturers, in part through the purchase of advanced equipment for distribution to member firms for testing, evaluation, and improvement.

The Michigan-based NCMS is a research consortium of approximately 150 U.S. companies established to promote cooperative R&D projects in advanced manufacturing. NCMS was established in 1986 to assist the machine tool industry. The center's mission has expanded to include "batch manufacturers" in the automobile, composite materials, and telecommunications industries.[91] The NCMS budget in 1991 was approximately $90 million, with $32 million provided by the Air Force Mantech program and the rest coming from member companies.[92]

The center's 60 full-time staff select R&D projects and research facilities, and distribute findings to member companies.[93] NCMS also supports "teaching factories" that use demonstration projects to foster employee education in computer-integrated manufacturing. With the exception of Canadian companies, NCMS excludes foreign firms from membership. NCMS reviews, on a case-by-case basis, requests to transfer R&D results to foreign subsidiaries of member firms.

In addition to efforts to increase technology links between private companies in collaborative R&D projects, such as SEMATECH and NCMS, a growing number of university-industry ventures have been established over the past two decades. Many of these involve federal funds. The National Science Foundation (NSF) University-Industry Cooperative Research Centers program was an experiment in building private joint ventures but using public matching funds during the start-up phase. A more recent program, the Engineering Research Centers (ERCs), also supported by NSF, has established multidisciplinary university R&D centers.[94] A similar initiative, the Superconductivity Pilot Centers, has been funded by the Department of Energy. State funds support cooperation between industry and academia in the North Carolina Microelectronics Center, which fosters cooperation between semiconductor manufacturing firms and faculty from colleges and universities located near Research Triangle Park in North Carolina. Many of these university-based cooperative R&D ventures focus on basic scientific research that is far from the commercialization stage of technology development.

There are many reasons for the increase in use of collaborative R&D to meet technology objectives. A primary reason is the lack of sufficient economic incentive for firms to invest in R&D. Research cooperation between firms can lower the cost of R&D whose results are not easily captured, or appropriated, by a single firm.[95] As noted elsewhere and as the research agendas of many of these cooperative ventures suggest, such R&D often extends beyond basic research.

Other motives for R&D cooperation include reducing duplication of R&D efforts within technology fields, the desire of firms to complement in-house research agendas, and an increasing need to monitor research in a broad array of scientific and engineering fields. The high costs of specialized equipment can be shared among a larger number of firms, and industry standards can also be developed through collaborative ventures. The potential benefits of cooperation can be substantial. There are barriers to successful cooperation, however, including determining the allocation of intellectual property rights, deciding on an optimal division of financial and R&D risks, and designing effective technology transfer mechanisms.

Just as there are many reasons for firms to cooperate in R&D, they are also organized in many different ways. Some cooperative ventures establish organizations with extensive, in-house R&D facilities. Others do not conduct in-house R&D but, rather, fund R&D performed in university laboratories. There is also considerable diversity in the technical objectives and agendas of individual collaborative R&D programs. It should be clear, therefore, that cooperative R&D projects are not a standard or simple form of executing technical alliances but include a complex array of different organizational structures and approaches.

Foreign Support for Collaborative R&D

Japanese Collaborative R&D Programs: Selected Examples

European and Japanese experiences with cooperative R&D ventures have stimulated considerable interest in the role of R&D collaboration in strengthening technological performance. Foreign governments, with varying degrees of success, have expanded their financial support for civilian technology development programs. The most prominent example of central government support for collective R&D efforts is Japan. The Japanese government not only has provided subsidies to industry-led programs in R&D but also has provided low-cost loans to companies for business development and equipment leasing.[96] In response to the perceived success of Japanese efforts and as a means of promoting economic integration, the Commission of the European Communities and a number of its member governments have also moved to promote collaborative R&D during the past decade.

The Japanese experience with collective research efforts dates to the 1961 Research Association for the Promotion of Mining and Industrial Technology Act. The act established Engineering Research Associations (ERAs) to increase the technical expertise of small and medium-sized companies. Ventures sponsored under the act are incorporated as nonprofit entities, with the government providing partial funding to the ERA.

Prior to the 1970s, ERAs did not focus on large-scale R&D projects involving advanced research on the cutting edge of science. In most instances they concentrated on a single technical barrier or technology-generation problem, with the objective of diffusing best-practice information on manufacturing product and process technologies. This information and much of the technological know-how diffused through collaborative ventures was based on technological advances outside Japan.[97] Collaborative R&D projects changed focus after 1970, however, under the general direction of the Ministry of Industrial Trade and Industry (MITI). New sets of "large-scale projects," including several well known in the United States—the Very High Performance Computer Systems, and Fourth Generation Computer Systems, among others—were started. It should be noted that not all collective research efforts in Japan, particularly those subsidized by the central government, have been successful in meeting their technical objectives.

Overall, 59 ERAs were established between 1971 and 1983 in fields including microelectronics, ceramics, and biotechnology.[98] By 1985, there were 50 ERAs still actively engaged in R&D.[99] Most projects aimed at advancing Japan toward technical parity with its major competitors. These ventures typically last from seven to ten years and have budgets of $100 million for the life of the ERA. Research work is performed at a member company or in one of the Japanese national laboratories. The results of any successful project are then licensed by the government to participants through the Japan Industrial Technology Association.

Through MITI and other Japanese ministries, the central government has provided financial support for R&D in several high-technology areas, including integrated circuits for television equipment, semiconductor research in the mid-1970s as part of the Very Large Scale Integration (VLSI) program, and computer-related technologies.[100] In some instances, the government provided grants and loans for private, joint R&D projects with the goal of bringing Japanese corporations up to world standards in technology. Along with this objective, the government has supported R&D in areas where generic, pre-commercial research has not been funded by the private sector. This type of R&D was supported by the government in order to strengthen the science and technology base, as well as to diffuse new, state-of-the-art technology.

Government funding of cooperative R&D projects through ERAs and large-scale "national projects," such as the VLSI program, undoubtedly played a part in Japanese industrial success in technological innovation.[101] Historically, however, few of these collaborative projects, including the large national projects, focused on research that could be characterized as "basic" in nature. In many cases, as in the VLSI project, research collaboration was employed as a means of supporting the diffusion of state-of-the-art industrial technology and practice among competing Japanese firms. Research and technology cooperation within Japan typically has been coupled with fierce competition among participants in the commercialization and application of the results of the collaborative research. Most of the research programs that received government funds have been closed to foreign participation. Some of these restrictions, however, have been removed in recent years. Many publicly supported cooperative research projects now appear to be open to foreign participation, subject to the payment of a share of project costs.

A considerable part of the Japanese government effort in collaborative R&D has focused on efforts "downstream" from basic research activities. Manufacturing extension services, capital subsidies, and accelerated depreciation for equipment have been used to promote technology development and, perhaps most important, the diffusion of new technologies in specific firms or industries, such as the machine-tool industry. Small and medium-sized companies benefit from programs funded by the government to provide technical assistance, grants for equipment leasing, and management assistance.

A relatively new mode of technology collaboration in Japan involves projects with government funding aimed at advanced research in technical fields with few technology leaders. One of the most visible and potentially important programs under way in Japan is the Key Technology Center pro gram.[102] The program objective centers on strengthening fundamental research within Japanese industry.

The Key Technology Center Program

The Japan Key Technology Center (KTC) program was established in October 1985 to promote research and development in advanced technologies. Its name is reflective of the Japanese government's belief that the stimulation of basic R&D in key technology areas is necessary to further economic development.[103]

The capital available for investment through the KTC program is provided by the sale of government holdings in the Japanese Tobacco Company (JNR) and Nippon Telephone and Telegraph Company (NTT).[104] Along with funds generated through the sale of stock in these companies, revenue generated by dividends of stock still held by the government flows to the KTC. Partial support is also drawn from the Japan Development Bank (JDB) and private sector sources.

There are two primary modes of operation for the KTC program: direct capital investment in consortia formed under KTC sponsorship and conditional loans offered at below-market interest rates to companies performing joint R&D. The KTC's loan program is targeted at applied R&D and prototype development projects. Loans are granted to companies engaged in joint ventures for five years. Proposals for joint projects that originate in the private sector include on average between eight and ten member companies.

As of the end of Japan fiscal year 1989, funds for the KTC investment programs totaled 20.2 billion yen (about $150 million), with approximately 47 percent contributed by the government, 23 percent by the JDB, and 28 percent by private companies.[105] The loan program operated with an additional 6.4 billion yen. A total of 77 capital investment projects had been started as of Japan fiscal year 1989.

The KTC also provides seed capital to consortia formed by two or more companies engaged in fundamental research or development projects. The KTC provides up to 70 percent of the capital requirements of any project for seven years. A second form of capital investment sponsored by the KTC provides up to 50 percent of the capital costs for "new media community" or "teletopia" development projects for a five-year period. All consortia formed specifically to engage in R&D, including foreign-based companies operating in Japan, are eligible for KTC funds. Each consortium formed under the KTC is a private company in which the KTC holds shares equal to its investment. Selection of the projects for both the loan and the investment parts of the program is made by a panel of experts, most often MITI officers, NTT, or the Ministry of Post and Telecommunications.

One KTC project is the Optoelectronics Technology Research Corporation (OTRC) established in 1986. It had its beginnings in a 1980 MITI-sponsored research project "Optical Measurement and Control System." This project produced the first-generation optoelectronic integrated circuits in Japan and demonstrated the capabilities of gallium arsenide devices. As is the case with other cooperative projects in Japan, successive generations of R&D projects are often built on past programs.

The OTRC's research agenda, formal planning mechanisms, and dialogue among industry, government, and academic researchers began early on in this first attempt at collective work. Lines between generic and proprietary R&D, a common framework for working together, and the division of labor are all decided over an extended tryout period. If successful, the venture may continue in other forms, as was the case for OTRC.

The OTRC has a total budget of 10 billion yen ($77 million; $1=130 yen), 7 billion of which is contributed by the KTC and 3 billion from member companies. The participants include Fujijura Ltd., Fujitsu, Hitachi, Matsushita, Mitsubishi, NEC, Nippon Sheet Glass Company, Oki Electric, Sanyo, Sharp, Sumitomo Electric Industries Ltd., Furukawa Electric, and Toshiba. The corporation is open to foreign membership.

The OTRC and its affiliated laboratory (OTRL) perform research on optoelectronic integrated circuits, which are a union of optical and photonic devices with electronics technology. This includes a major emphasis on atomic-scale controlled epitaxy and maskless fine pattern formation to produce multidimensional superlattice structures. Research is divided into programs on atomic-scale epitaxy, beam-assisted pattern formation, the characterization of surfaces and interfaces with the atomic scale, and quantum solid-state physics.

The main OTRC laboratory is located in Tsukuba Science City outside Tokyo. The 14 member companies each operate "shadow" projects at their corporate facilities. These focus on device research and are divided into 14 individual groups. The head office of the OTRC includes a president and a vice president, both former MITI officials. The day-to-day operation of the laboratory is under the direction of a managing director and senior researcher on leave from Toshiba. Technologies developed by OTRC will be owned by member companies. Intellectual property rights in other MITI-sponsored projects, such as research at the Institute for New Generation Computer Technology (ICOT), the VLSI Project, or other large-scale R&D programs are owned by the government.

Like other KTC projects, the OTRC is evaluated every year by a panel of independent university professors. The review process is coordinated under MITI direction. The technical program at OTRC is not under the control of any government employees, but rather is directed in a consultative way by staff at member companies.

It is premature to provide an assessment of OTRC's success in support of Japanese commercialization efforts. Its programs have been in operation for only several years. There are characteristics of the program that, however, provide insight into the utility and potential barriers to cooperative R&D. First, member companies have been hesitant to send senior-level, qualified staff to the laboratory in Tsukuba. Although this may inhibit the technology transfer process if technologies are successfully developed at OTRL, the director of the laboratory believes that the "quality of staff" issue has been overstated in both Japan and the United States, at least as it relates to cooperative R&D ventures.[106]

Although most member companies apparently do not send their senior researchers, managers of the program do not believe this is critical to the success of the venture. They stress the importance of R&D investments and quality of staff in the company laboratories as key to the success of the project. It is at the point of contact in the "shadow" project in each member's corporate laboratory that qualified staff and other investments may be most important. One of the most pressing concerns of management is that the coordinating researchers at member laboratories be able to tailor research results from OTRL to applied R&D and prototype development in the commercialization stages.

The emphasis on in-house R&D investments to complement the cooperative R&D effort and industry commitment of quality staff in corporate laboratories is often overlooked in evaluations of the factors contributing to success or failure in cooperative R&D. In fact, the Japanese experience strongly suggests that cooperative R&D can rarely serve as a substitute for, but should more properly be seen as a complement to, in-house research. Moreover, the importance of technology diffusion objectives in Japanese programs, including those targeted at research in generic R&D, is critical to understanding the utility of cooperative programs. In many cases, as the Japanese experience suggests, cooperative R&D may support technology adoption and dissemination as effectively as it supports technology creation.

Any insights into collaborative R&D or the appropriate government role in supporting technology advancement gained from the Japanese experience must take into account fundamental differences in the structure of industrial R&D in different countries.[107] Japanese industry funds a relatively higher percentage of total R&D than does industry in the United States (70 versus 50 percent).[108] Moreover, the larger share of resources devoted to defense-related R&D in the United States and different perspectives on the division between pre-commercial and proprietary R&D complicate comparisons of projects in the United States and Japan.

Cooperative ventures certainly contributed to postwar technical advances in Japan, especially during recent decades. They did so in conjunction with policies that supported high levels of domestic savings and investment, stable fiscal and monetary policies, high rates of investment by firms in in-house R&D, and a willingness by the Japanese government and industry to invest in human capital. Collaborative R&D projects provided incentives to pre-commercial R&D investment, as well as advanced Japanese applied R&D capabilities. They also encouraged the adoption and diffusion of new technologies in Japanese firms. It is particularly in this last area—technology diffusion—that some of the most important contributions have been made.[109]

Government-and nongovernment-sponsored projects in Japan center primarily on raising the technical standards of Japanese firms to international levels. They most often focus on improving the capabilities of firms to absorb, adapt, and incorporate new knowledge and technology into commercial products and processes. Cooperation in research is complemented by strong competition in the application of results.

The fact that management of most cooperative R&D programs in Japan is the direct responsibility of corporate R&D affiliates and program personnel may also contribute to successful execution of R&D programs. Government agency oversight or management is usually indirect and serves only as a channel through which the private sector actors communicate in a neutral forum. MITI and other Japanese government agencies generally do not provide direct guidance on research agendas, personnel and staffing decisions, or follow-on work plans.

Moreover, cooperative R&D in Japan is often conducted through an independent quasi-governmental organization. A separate, for-profit venture, like the KTC, is set up to arbitrate disputes and serve as the mechanism through which participants share the risks and rewards of joint effort. In addition, collaborative R&D projects in Japan have promoted private sector investment in basic, nonproprietary R&D. In certain instances, in selected industry sectors, they could serve a similar purpose in other countries. Japanese collaborative R&D projects also appear to have strengthened the ties between government and industry through consultative mechanisms set up to promote, monitor, and evaluate cooperative ventures. Most of these programs are not direct technology subsidies, but rather cost-sharing partnerships that are evaluated at regular intervals.

There is also considerable anecdotal and other evidence suggesting that collaboration among otherwise fiercely competitive Japanese firms in a given industry has rarely been easy. Many of the tensions that have arisen in recent U.S. efforts at R&D cooperation have also been present in Japanese collaborative ventures. Indeed, as the direct influence of MITI and other government agencies over Japanese firms has declined, and as many of these firms reach positions of considerable technological strength, collabo ration among Japanese firms may become a less common and important element of Japanese technology policy.

European Cooperative R&D Projects: Selected Examples

European governments have also sought to promote industrial research, development, and technology commercialization through financial incentives for collaborative R&D. During the 1970s, European governments devoted significant attention to joint industry-government projects involving small and medium-sized firms. They also worked to build links between universities and industries in R&D, most often in early-stage research.[110] Beginning in the early 1980s, government science and technology policies increasingly focused on emerging technologies and large-scale, pan-European collaborative R&D projects. This has been particularly true in areas such as information technology and biotechnology. As in the United States, a major objective of recent European technology initiatives has been forging technical alliances in pre-competitive research. The planned economic union of the European Community (EC) in 1992 has generated interest in standard setting and economic integration as methods of promoting technological advance. The need to blend economic, technological, and political goals in the organization and focus of many EC projects may have contributed to their organizational complexity and multiple objectives.

The most notable efforts in collaborative R&D in Europe have been managed under the Framework R&D Programs of the European Community.[111] The Framework Programs will allocate approximately $8.4 billion from 1990 through 1994 for programs in information processing, communications, materials, measurements and testing, biotechnology, and energy, among others.[112] The ESPRIT (European Strategic Programme for Research and Development in Information Technology) programs are aimed at pre-competitive research and economic integration[113] in flexible manufacturing, information processing, microelectronics, office automation, and software.[114] ESPRIT received funding of $1.8 billion during its initial phase (1984–1989) and will spend more than $2 billion in 1990–1995. Government funds are matched by industry participants. The aim of RACE (Research and Development in Advanced Communications Technology for Europe) is to standardize telecommunications technologies into a digitized broadband network.[115] The BRITE (Basic Research in Industrial Technology) program is developing technologies in advanced manufacturing. A collaborative program in biotechnology is attempting to coordinate R&D programs and standard setting of various countries.[116]

Europe has a number of collaborative R&D programs in operation outside the Framework Programs structure. The EUREKA project, begun in

1985 (partly as a response to technology developments expected to emerge from the U.S. Strategic Defense Initiative), is targeted at cross-national links between research institutes and private industry. EUREKA's $6.5 billion budget supports approximately 300 projects in 19 countries in robotics, microelectronics, telecommunications, and other advanced technologies. EUREKA's most significant initiative may be JESSI, an eight-year, $4.4 billion project to manufacture 64-megabyte semiconductors.[117]

In addition, companies in Germany, France, the United Kingdom, and Spain have received several billion dollars in government subsidies to develop jet aircraft through the Airbus consortium.[118] There have also been a number of national science and technology projects. Prominent among these in the 1980s was the United Kingdom's five-year, £200 million Alvey program to improve university-industry collaboration in pre-commercial R&D in information technologies.[119]

The tangible benefits of many of these efforts are far from evident. Most large-scale R&D programs under the European Community's sponsorship, in particular, have been in operation for less than 10 years. One potential problem with EC R&D efforts, however, is the wide dispersion of technical and financial resources among many participants. Many R&D projects involve 40 to 50 individual partners. Other characteristics of European programs may also contribute to less than successful results. Collaborative programs have, in some cases, employed direct subsidies without requirements for matching industry contributions, which provides a weak link to market signals on promising technology applications. The complex administrative structure of EC programs may further contribute to uncoordinated program goals and a lack of clarity in technical agendas.

In addition, as evident in the telecommunications field, for example, a lack of regulatory and technical standards may complicate EC R&D efforts.[120] In general, both the EC and the EUREKA projects have restricted the participation of foreign firms. IBM-Europe participates in part of the ESPRIT and EUREKA programs (within the latter, primarily the JESSI project). There are few other examples of foreign participation in these programs and none of full membership in a consortium. For example, after its acquisition by Fujitsu, ICL, a British computer firm, had its role in EUREKA and ESPRIT considerably restricted.

Regional European programs in collaborative R&D coexist with a number of initiatives in domestic R&D collaboration within member states. The French Filiere Electronique and the British Alvey programs are among the best-known examples of these. Recent evaluations of the Alvey program in Britain (which was terminated in 1989) provide further insight into the possibilities and potential weaknesses of cooperative R&D programs, as developed in Europe.[121]

Alvey was centered on pre-commercial R&D in the telecommunications sector and involved computer manufacturers, universities, and electronics firms in multiple R&D consortia. Although the emphasis on pre-commercial R&D may have been appropriate and many of the technical goals were accomplished, the program failed to effectively promote the adoption of new knowledge generated through the venture. Success in meeting technology development and research goals does not, therefore, guarantee project success. Moreover, one assessment found that firms participating in the software engineering ventures sponsored under Alvey neglected to devote sufficient attention to in-house R&D projects linked to the consortia's agenda.[122] Cooperation cannot substitute for investment by firms in in-house R&D capacities. Finally, although valuable research results were generated, the lack of government support for diffusing the technology among participating firms and of incentives to bridge the R&D phases to commercialization efforts may have hindered the program's impact on the United Kingdom's information technology base.

Summary

Most private and mixed public-private cooperative R&D programs established over the past decade are, in the broadest context, attempts to address apparent weaknesses in a nation's scientific and technological infrastructure. Cooperative R&D ventures can play a role in support of this objective. One of the most important potential benefits of cooperative R&D is the promotion of technology diffusion and adoption, a weakness in recent U.S. technological performance. Japanese cooperative R&D programs, in particular, have been established with this objective and have exhibited success in raising the technical standards of Japanese industry. The Japanese government has also acted to promote the transfer of information on best practice and the introduction of new process technologies. In the United States, SEMATECH may play a role in the diffusion and adoption of semiconductor manufacturing equipment. Collaborative R&D may also be useful in projects beyond basic research, in pre-commercial technology development. Chapter 3 outlines areas in which federal support of collaborative projects at this stage merits attention and there may be a legitimate federal role in providing financial incentives to industry-government partnerships.

Collaboration in R&D is successful when technology is transferred to member firms and adopted as a result of the collaborative effort. This typically requires a significant commitment of resources by private firms, both to the cooperative venture and to the support of parallel research within member firms. Coordination of in-house R&D capabilities, personnel, and strategic plans with the management of collective projects is necessary. Establishing channels for assigning high-quality researchers to the coopera tive venture, and rotating them to and from member firms, is also critical to the success of technology transfer. Collaborative ventures should be administered as profit-making ventures, complete with budgets, schedules, and project milestones, as well as clear guidelines on intellectual property rights. The mission and goals of these projects must be clearly established from the start. In many cases, the Japanese experience suggests that the most appropriate objectives may be those that focus on technology adoption, and on the dissemination and refinement of new concepts, rather than frontier basic research. Cost-sharing provisions are also important in these projects. They strengthen links between the collaborative R&D programs and the research efforts of participants, as well as improve the ties to potential commercial market applications (Chapter 3 discusses these issues in greater detail). Government funds should not be the sole source of support for cooperative research ventures.

Several of the European experiments in collaborative R&D are especially informative in this regard. Direct subsidies to inefficient industries or R&D grants through cooperative projects to meet political agendas dilute the effectiveness of government leverage of technology strengths in private industry. Finally, as the Japanese experience with government-industry collaborative R&D indicates, independent program evaluation and termination of unsuccessful collective projects are important.

Finally, it is important to note that cooperative R&D projects are not the only methods of promoting national technology policy goals. The Japanese experience suggests that such projects supplement innovative efforts and investments made in a stable economic environment with a relatively low cost of capital and a highly skilled labor force.

Technology Adoption

As noted in Chapter 1, the adoption of new technologies is an important part of the processes through which innovation contributes to economic growth and rising standards of living. The limited data available on rates of adoption in the United States in new manufacturing processes, such as numerically controlled machine tools and robotics, however, show that U.S. firms have been relatively slow to incorporate these technological advances.[123] The dissemination and use of office automation equipment have, in contrast, been relatively swift compared to other nations.

In general, nations whose manufacturing firms adopt new technologies have policies that favor adoption. In the United States, the federal role has centered almost exclusively on basic research and development. Initiatives to promote adoption and diffusion have been rare. Although the United States often has an advantage in leading-edge technology, it has suffered from an inability to apply technology appropriate to the actual needs of its manufacturers.[124]

As noted earlier in this chapter, federal support for agricultural research and technology development included substantial funding for programs in the adoption of new agricultural technologies. Much less funding has been provided by federal and state government sources to support industrial technology extension and adoption. Industrial extension policies have received greater attention and small increases in state and federal funding during the past 10 years. Funding for industrial extension remains modest, however, especially when compared to the estimated $1.3 billion invested in agriculture extension activities in the United States ($398 million of which comes from federal sources).[125] The United States has devoted limited resources to technology diffusion and assistance to firms to adopt new or existing manufacturing technologies.

Over the past two decades, state governments have moved to establish a dominant role in programs to facilitate technology adoption and diffusion.[126] State governments design and administer most industrial extension programs and are collectively the largest provider of funds for extension activities. Technology-related programs at the state level range from business and technology assistance to provision of capital and support for research centers.[127] In particular, several states have established networks of local agents through which assistance is offered to firms hoping to incorporate new technology in manufacturing processes. Among the most comprehensive state-based extension programs is the Georgia Institute of Technology's Research Institute (GTRI). Programs administered by GTRI include industrial extension services, and in-house R&D facilities and demonstration projects—all geared to small and medium-sized firms in Georgia.[128] There are other examples of state-based extension programs that could serve as mechanisms through which federal assistance to firms in technology adoption might be facilitated.

To date, however, there have been only limited experiments with federal industrial extension programs. The 1988 Omnibus Trade and Competitiveness Act authorized new federal programs in industrial extension and demonstration projects in manufacturing technology. The five state-based Manufacturing Technology Centers (MTCs) of the National Institute of Standards and Technology, which stress technology transfer and incorporation of existing technology in manufacturing processes, received federal appropriations of $12.4 million in FY 1991. In January 1992, NIST announced the competition for the establishment of two new centers.

The MTC program's objective is to "enhance the productivity and technological performance in United States manufacturing."[129] MTCs work by transferring manufacturing technology and technical information developed at NIST and other federal facilities to small and medium-sized firms. The MTCs, established to serve specific regions of the country, include the Great Lakes Manufacturing Technology Center in Cleveland, Ohio; the Northeast Manufacturing Technology Center at Rensselaer Polytechnic Institute in Troy, New York; the Southeast Manufacturing Technology Center at the University of South Carolina in Columbia, South Carolina; a center in Ann Arbor, Michigan, located at the Industrial Technology Institute; and one at the Kansas Technology Enterprise Corporation in Topeka, Kansas.

The nonprofit organizations selected to operate the MTCs provide 50 percent of the operating funds for the centers for three years. NIST provides the remaining 50 percent of each center's operating funds, with contributions declining each year to 20 percent in the sixth (final) year of federal funding. Each center is expected to be financially independent after six years. The National Research Council reviews applications for the centers for technical merit, and the NIST director selects the awardees.

On average, each MTC receives approximately $3 million per year. There are no guarantees of continued funding past the first-year grants; each center is reviewed annually by NIST, with a third-year comprehensive review mandated by the 1988 Trade Act.[130] A review panel is appointed by the director of NIST and chaired by an official from the institute. The final report on each center is delivered to the Secretary of Commerce.

The MTC program has been in operation for only three years, and its impact on small and medium-sized firms in technology adoption and transfer remains uncertain. The panel that conducted the third-year review concluded that the centers were meeting general technical objectives and recommended continued funding.[131]

In addition to the MTC program, $1.3 million in federal funds was appropriated in FY 1991 for the State and Local Extension Initiatives programs.[132] The remainder of the current federal effort in technology extension includes the Trade Adjustment Assistance program funded at $12.9 million, which is designed to help firms adversely affected by imports.[133]

There are few examples of U.S. government program to diffuse manufacturing technologies. However, there have been federal projects to diffuse agricultural R&D and energy-related technologies. Agricultural extension programs have assisted in the strong rate of growth in agricultural productivity.[134] Energy demonstration projects of the 1970s constituted one of the few other federal programs in technology diffusion. (In many cases, these projects were not designed to facilitate the adoption of a well-understood and "debugged" technology. They were targeted at advancing technology development while also accelerating adoption.) The energy projects apparently did little, however, to accelerate technology adoption.

Lessons from small-scale efforts to support technology adoption by

U.S. firms indicate several areas for improvement in program design. High costs and limited results of the energy demonstration projects suggest the importance of diversifying federal support for technology diffusion and development across a broad range of technological possibilities. Other factors that contribute to program success are stable sources of long-term financial support, decentralized control over program design, and outreach to firms. The latter is necessary to ensure that those who develop technology are responsive to user needs.

Some foreign governments invest in industrial extension services designed to help small and medium-sized firms collect and apply new technologies. Some of these programs have exhibited success in raising the technical competence of workers and firms. An important goal of cooperative research supported by Japanese industry and government, as noted, is the dissemination of new technology, rather than extension of the technological frontier. The Japanese federal and prefectural governments devote significant funds to testing and consultation centers for small and medium-sized manufacturing firms. This effort is part of larger programs in technical and financial assistance for technology adoption. Japan fostered the use of numerically controlled machine tools, for example, through technology extension services, low-cost leasing arrangements, and rapid depreciation of equipment. Similar programs are administered by provincial governments in Germany.

The adoption of most new technologies is directly linked to investment decisions, as well as to the rate of gross domestic capital formation. Economic factors affecting capital formation, therefore, may influence international differences in the rate of adoption of new technologies. When compared to manufacturing sectors of other industrial economies, the slower rate of growth of U.S. labor productivity in manufacturing may explain part of the relatively weak U.S. performance in technology adoption. The U.S. shortcomings in primary and secondary education, discussed in Chapter 1, and in work force training and retraining, are also important factors. As to the latter, U.S. programs for training and retraining workers are quite modest. Most employee technical training assistance provided by firms is directed at white-collar workers.[135]

Summary

An important way in which the economic benefits of technology are realized is through their adoption by industry. For several reasons, the United States can no longer depend on its advantage in technical innovation and basic research to translate into a lead in commercial competitiveness. Scientific and technological progress in other countries challenges U.S. lead ership in technology and innovation. The globalization of industrial production and rapid improvements in international communication and transportation systems have reduced the advantage gained by the firm or nation that develops new technology. The rate at which innovations flow across international boundaries has sharply increased.[136]

Difficulties faced by firms in commercialization are often associated with incremental improvements to products and processes (in contrast to revolutionary technical breakthroughs) in modern manufacturing facilities. The time frame during which research findings can be effectively utilized in commercial products is narrowing. This places higher premiums on the ability of firms to quickly apply knowledge and adopt new technology.

Furthermore, the “window” during which the early commercializer of a new technology reaps economic benefits has diminished, particularly in industries such as microelectronics, automobiles, and consumer electronics. The effects of rapid technology adoption on productivity, product quality, and ultimately, living standards are likely to be much greater in the competitive environment in which U.S. firms now find themselves. The firm or firms that successfully commercialize or adopt new technology may gain a significant lead over competitors, whether or not those competitors are responsible for the generation of the new technology. The United States, therefore, needs a better balance in civilian technology policy, one that takes into consideration the importance of diffusing best-practice information and the adoption of new technology.

Better information, data, and independent analysis on technology adoption are necessary. An evaluation of rates of adoption in the United States and overseas, factors affecting the ability of U.S. and foreign firms to incorporate new technologies into the production process, and a comparative analysis of public policies that might support adoption should be undertaken. Studies to inform public policy should be conducted on technology adoption, focusing on data about rates of technological diffusion throughout the economy.[137] **Better analysis of factors that may contribute to different rates of adoption in the industrialized nations, such as the cost of capital and labor, is necessary.**[138] **A clearer consensus on reasons for international differences in the rate of technology adoption would help tailor U.S. policies to meet the needs of industry.**

Although there is a need for specific information on and analysis of technology adoption and diffusion, the federal government does have a legitimate role in support of U.S. firms in this area—one that should take shape in the short term. Increased federal government support for programs that facilitate the rapid adoption of new technologies in U.S. industry is necessary.

The panel, therefore, recommends the establishment of a national program in industrial extension. The Department of Commerce is the most appropriate agency for any new federal initiative to assist U.S. firms in adopting new manufacturing process and product technologies.

The Technology Administration at the Department of Commerce is currently charged with the responsibility to aid industry in a wide range of areas, including the transfer of technology, the commercialization of federally funded R&D to industry, and the adoption of advanced manufacturing techniques by small and medium-sized firms. The National Institute of Standards and Technology also manages programs in technology adoption. These programs are, however, small-scale efforts that have suffered from inadequate funding and staff resources. Specifically, although the MTC program at NIST has the potential to serve a limited client base in regions where it is established, a more comprehensive, nationwide service for the 350,000 small and medium-sized firms is necessary to impact technology adoption rates in the United States in a significant manner. This new program could leverage the resources available through the MTCs, as well as state-based programs, to better accomplish technology adoption and extension goals.

The panel recommends the establishment of an Industrial Extension Program (IES) at the Department of Commerce. The IES would assist industry to absorb technical information on best practice in manufacturing systems from both foreign and domestic science and engineering sources, and would disseminate information on new technologies through regional offices managed by the Department of Commerce.

CONCLUSION

This chapter outlines selected federal programs that support civilian technology development. It assesses both strengths and weaknesses in the current national system to support private sector technology. The panel concentrated its efforts on those programs that, in its judgment, both require significant changes and have the potential to contribute in a substantial manner to U.S. performance in technological innovation. Additional material on federal agencies and their role in pre-commercial R&D is presented in the following chapter.

There need to be substantial changes in the framework that supports civilian technology development in the United States. This conclusion is based on our assessment that post-war federal science and technology policy needs to be reevaluated. There have been fundamental changes in the economic and technological environment in which U.S. companies compete. There have been great benefits from federal support of basic scientific research, and a strong rationale continues for that public funding. We believe, however, that the almost exclusive focus of federal technology policy on investments in basic R&D should be modified.

There is a strong case for extending the federal role beyond the funding of basic R&D. This is true both on economic grounds and because government programs have had some success in the past in stimulating civil technology development and commercialization. A new federal role in support of private technology efforts should be shaped through investments in pre-commercial R&D, as well as projects to increase the rate of technology adoption in U.S. firms. These are the areas, as we have shown, in which the potential exists for great public benefit, and U.S. firms cannot appropriate sufficient economic benefits from private investment.

To strengthen U.S. comparative advantages, a reorientation of priorities in the system that provides long-term support for military technology development is necessary. This change would benefit both the nation's military and its civilian technology infrastructure. Specifically, we believe that the mandate and objectives of the Defense Advanced Research Projects Agency should include the explicit support of dual-use technology to bolster commercialization efforts in the civilian sector.

The U.S. approach to stimulating transfer from government laboratories that has characterized technology transfer policies and congressional initiatives over the past decade is misguided. Although the laboratories constitute a significant public good, most of the work at these facilities is unlikely to serve the commercial needs of the civilian sector. The administration should therefore select only a few of the several hundred government laboratories to be involved in technology transfer activities. Changes in the mission and objectives of these laboratories will require significant additional funding and personnel. In the few laboratories with the potential to serve commercial needs, it will be necessary to commit resources, over and above current appropriations, in order to meet technology transfer goals set under this new framework.

A strengthened federal role in civilian technology and reorientation of government policies beyond investment in basic scientific research will require more than simply changes in technology transfer policies or additional federal funding for pre-commercial activities. A significant new emphasis is needed on the performance and ability of U.S. firms to adopt new technologies. We have shown that although U.S. performance in technology generation remains strong, the nation's industries are having increasing difficulty incorporating new technology into the production process, particularly the rapid introduction of incremental improvements in product and process technologies. Better information and analysis are necessary on technology adoption in the United States and overseas, with the goal of providing a basis upon which new federal responsibilities in this area can be determined.

NOTES

1. U.S. Department of Commerce, *Advanced Technology Program, Proposal Preparation Guidelines* (National Institute of Standards and Technology, Gaithersburg, Md., 1990), 2.

2. An early study of the returns from investment in agricultural R&D, as well as extension services, found a marginal rate of return on investment in R&D of 53 percent; see Zvi Griliches, "Returns Expenditures, Education, and the Aggregate Agricultural Production Function," *American Economic Review* (1964), as cited in Edwin Mansfield, "Microeconomics of Technological Innovation," in *The Positive Sum Strategy*, eds. Ralph Landau and Nathan Rosenberg (Washington, D.C.: National Academy Press, 1986), 308.

3. Technical change and technological innovation constitute a primary source of economic growth. The contribution of technical change to growth was first examined in the work of Robert Solow, "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics* 23 (August 1957):101–108 and Moses Abramovitz, "Resource and Output Trends in the U.S. since 1870," *American Economic Review* 46 (May 1956). See also Martin N. Baily and Alok K. Chakrabarti, *Innovation and the Productivity Crisis* (Washington, D.C.: The Brookings Institution, 1988); John Kendrick, "Productivity Trends in the United States," in *Lagging Productivity Growth*, eds. Shlomo Maital and Noah M. Meltz (Cambridge, Mass.: Ballinger Publishing Co., 1980); and Edwin W. Mansfield, "Economic Effects of Research and Development: The Diffusion Process and Public Policy," in *Planning for National Technology Policy*, eds. Richard A. Goodman and Julian Pavon, (New York: Praeger, 1984), 104–120, among others.

4. For estimates of the social and private rates of return on investment in specific innovations, see Edwin Mansfield et al., "Social and Private Rates of Return from Industrial Innovations," *Quarterly Journal of Economics* (1977); Robert R. Nathan Associates, *Net Rates of Returns on Innovations*, Vol. 1 and 2 (Report prepared for the National Science Foundation, Washington, D.C., 1978); and Foster Associates, *A Survey on the Net Rates of Return on Innovations*, 3 volumes (Report prepared for the National Science Foundation, Washington, D.C., 1978).

5. For an overview of analyses of the rationale for federal investment and social returns on R&D investment that accompany lack of private sector incentives for investment, see U.S. Congress, Congressional Budget Office, *Federal Support for R&D and Innovation* (Washington, D.C.: U.S. Government Printing Office, 1984).

6. For a discussion of these policies, see Harvey Brooks, "National Science Policy and Technological Innovation," in *The Positive Sum Strategy*, eds. Ralph Landau and Nathan Rosenberg (Washington, D.C.: National Academy Press, 1986), 119–167.

7. U.S. Congress, Office of Technology Assessment, *Federally Funded Research: Decisions for a Decade* (Washington, D.C.: U.S. Government Printing Office, 1991), 3; and National Science Board, *Science and Engineering Indicators—1989* (Washington, D.C.: National Science Board, 1989), appendix table 5–17.

8. National Science Board, *Science and Engineering Indicators—1989* , 231. Figures are for 1988.

9. Thomas H. Lee and Proctor P. Reid, eds., *National Interests in an Age of Global Technology* (Washington, D.C.: National Academy Press, 1991), 23–24, 27–29.

10. David C. Mowery and Nathan Rosenberg, *Technology and the Pursuit of Economic Growth* (New York: Cambridge University Press, 1989), 209–210.

11. For example, there are restrictions on "foreign participation" in SEMATECH, the National Center for Manufacturing Sciences, federal laboratory R&D programs, and the Advanced Technology Program at the National Institute of Standards and Technology. In Japan, however, there is a current emphasis on the inclusion of foreign multinational corporations and affiliates of U.S. firms based in Japan in Japanese government-sponsored R&D projects. See Chapter 3 for further discussion of this point.

12. The Homestead Act of 1862 granted 160 acres of soil to persons settling on and cultivating land for five years. The Morrill Land-Grant Act of the same year gave every state and territory 30,000 acres of public land for each congressional representative. The allotments of land, for use by agricultural and mechanical colleges, spurred the development of a system of land grant colleges that provided the framework for a U.S. research system in agriculture. In addition, a "Commission" (later Department) of Agriculture was established during the Civil War to guide federal investments in agriculture. Outbreaks of Texas fever and pleuropneumonia and European restrictions on the import of U.S. meat suspected of carrying disease prompted Congress to establish a Bureau of Animal Industry within the new Department of Agriculture in the early 1900s. Research conducted by the bureau was instrumental in finding technical solutions for reform of the meat packing industry.

13. See, for example, Robert E. Evenson and Wallace E. Huffman, "Supply and Demand Functions for Multiproduct U.S. Cash Grain Farms: Biases Caused by Research and Other Policies," *American Journal of Agricultural Economics* 71 (August 1989):761–773.

14. The Hatch Act remains the principal mechanism for federal funding of agricultural research.

15. Act of 1906 for the Further Endowment of Agricultural Experiment Stations (Adams Act).

16. Norwood Allen Kerr, *The Legacy, A Centennial History of the State Agricultural Experiment Stations, 1887–1987* (Columbia: University of Missouri, 1987).

17. John S. Wilson, *Productivity and Competitiveness: Industrial Extension Services and Technology Transfer Programs in the U.S.* (Washington, D.C.: The World Bank), 8.

18. Richard R. Nelson, ed., *Government and Technical Progress* (New York: Pergamon Press, 1982), 269.

19. Kenneth Flamm and Thomas L. McNaugher, "Rationalizing Technology Investments," in *Restructuring American Foreign Policy*, ed. John D. Steinbruner (Washington, D.C.: The Brookings Institution, 1989), 126.

20. Information provided by the IBM Corporation, Armonk, New York.

21. Prior to the 1950s, federal support of the industry—typically involving collaboration of government, industry, or universities—was essential in medical discoveries. Pharmaceutical companies, the Department of Agriculture, the Rockefeller Foundation, and the Office of Scientific Research and Development (OSRD) pooled resources during World War II to make penicillin, first discovered in 1928, widely available for the armed services. OSRD produced the antimalarial drug quinacrine through an analysis of substances developed by university and pharmaceutical company researchers. During this period, the OSRD Committee on Medical Research awarded $25 million in contracts to universities, hospitals, and companies.

22. P.L. 78–410.

23. Stephen P. Strickland, *The Story of the NIH Grants Program* (Lanham, Md.: University Press of America, 1989), 44.

24. NIH Budget Office. Figures are for dollars actually spent.

25. Michael R. Pollard, "Selected Examples of Government and Industry Collaboration in Pharmaceutical Research and Development," in *Government and Independent Collaboration in Biomedical Research and Education: Report of a Workshop* (Washington, D.C.: National Academy Press, 1989), 4.

26. Figures are for fiscal year 1991. NIH's share of the genome project is $87 million; DOE's share is $47 million. See "DoE's Genome Project Comes of Age," *Science* (April 26, 1991):498.

27. David C. Mowery, *Collaborative Research: An Assessment of Its Potential Role in the Development of High Temperature Superconductivity* (Paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, D.C., 1988), 47.

28. Industrial Biotechnology Association.

29. Wendy Schacht, *Commercialization of Technology and Issues in the Competitiveness of Selected U.S. Industries: Semiconductors, Biotechnology, and Superconductors* (Paper prepared for the Congressional Research Service, Washington, D.C., 1988), 33.
30. Cassius J. Van Slyke, "New Horizons in Medical Research," *Science* 104 (December 13, 1946):561.
31. Roger E. Bilstein, *Orders of Magnitude: A History of the NACA and NASA, 1915-1990* (Washington, D.C.: National Aeronautics and Space Administration, 1989), 3.
32. David C. Mowery, "Federal Funding of R&D in Transportation: The Case of Aviation" (Paper presented at the COSEPUP Workshop on the Federal Role in Research and Development, National Academy of Sciences, Washington, D.C., 1985), 315.
33. Alex Roland, *Model Research, the National Advisory Committee for Aeronautics*, vol. 2 (Washington, D.C.: National Aeronautics and Space Administration, 1985), 489.
34. Mowery, *Collaborative Research*, 71.
35. John V. Becker, *The High-Speed Frontier, Case Histories of Four NACA Programs, 1920-1950* (Washington, D.C.: National Aeronautics and Space Administration, 1980), 117-118.
36. Energy Security Act of 1980.
37. Roger G. Noll and Linda R. Cohen, *Economics, Politics, and Government Research and Development* (Paper commissioned for a Workshop on The Federal Role in Research and Development, Committee on Science, Engineering, and Public Policy, National Academy of Sciences, Washington, D.C., November 21-22, 1985), 11.
38. John Deutch, *Commercializing Technology: What Should DoD Learn from DoE?* (Center for International Security and Arms Control, Stanford University, 1990), 6.
39. U.S. Congress, Congressional Research Service, "Synthetic Fuels Corporation," *Congressional Research Service Review* (September 1984), 23.
40. Hans H. Landsberg, "The Death of Synfuels," *Resources* 82 (Winter 1986): 7.
41. Deutch, *Commercializing Technology*, 5, 8.
42. This policy contrasted with the production and purchasing subsidies granted synthetic fuels and solar heating, despite the fact that these industries were also at an early stage of technology maturation.
43. "Systems vs. Technology: DARPA at a Crossroads?" *Armed Forces Journal International* 127 (November 1989): 71.
44. Burton I. Edelson and Robert L. Stern, *The Operations of DARPA and Its Utility as a Model for a Civilian ARPA* (The Paul H. Nitze School for Advanced International Studies, Washington, D.C., 1989), F1-2.
45. For an overview of DARPA and its role in dual-use technology development, see Mowery and Rosenberg, *Technology and the Pursuit of Economic Growth*, 137-156. It should be noted that DARPA has had a limited role in microelectronics R&D. Government procurement policies provided primary incentives for the formation of the computer industry in the 1950s and early 1960s, with advanced R&D work playing a much less important part. In the late 1960s and since, DARPA's R&D work has had a major role in new technology, and government procurement has shrunk as a fraction of the industry.
46. John A. Alic and Dorothy Robyn, "Designing a Civilian DARPA," *Optics and Photonics News* 1 (May 1990): 19.
47. DARPA. Figures are direct appropriations for FY 1991.
48. Edelson and Stern, *The Operations of DARPA and Its Utility as a Model for a Civilian ARPA*, 6-7, 18.
49. "A New Government Role in Key Industries," *The Washington Post* , April 26, 1990.
50. Carnegie Commission, *New Thinking and American Defense Technology* (Washington, D.C.: Carnegie Commission, 1990), 24-25.
51. Ibid., 26.

52. Edelson and Stern, *The Operations of DARPA*, 22-23.
53. Alic and Robyn, "Designing a Civilian DARPA," 21.
54. Edelson and Stern, *The Operations of DARPA*, 16.
55. For specific suggestions on improving technology flow between defense agencies and the private sector, see Carnegie Commission, *New Thinking*, 24-25.
56. See U.S. Congress, General Accounting Office (GAO), *Federal Research: Small Business Innovation Research Program Shows Success, but Could Be Strengthened*, T-RCED-92-3 (Washington, D.C.: U.S. Government Printing Office, 1991); and Small Business Administration (SBA), Testimony of Richard Shane, Assistant Administrator, Office of Innovation, Research and Technology, before the House Small Business Committee, U.S. House of Representatives on the Small Business Innovation Research Program, U.S. Congress, October 3, 1991. Both GAO and SBA will be releasing reports on the SBIR program and technology commercialization in early 1992.
57. Small Business Innovation Development Act.
58. Along with NIST, other agencies within the Technology Administration whose functions relate to industrial competitiveness include the Clearinghouse on State and Local Initiatives, the Japanese Technical Literature Program, the National Technical Information Service, the Office of Technology Policy, and the Office of Commercial Policy.
59. U.S. Department of Commerce, *Research, Services, Facilities: National Institute of Standards and Technology* (Gaithersburg, Md.: National Institute of Standards and Technology, Technology Administration, 1991).
60. Section 5131 of the Omnibus Trade and Competitiveness Act (P.L. 100-418) authorized ATP.
61. U.S. Department of Commerce, *Advanced Technology Program, Proposal Preparation Guidelines* (U.S. Department of Commerce, Washington, D.C., 1990).
62. Personal communication from George Uriano, director of Advanced Technology Program, to Ed Moser, Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, Washington, D.C., February 22, 1991.
63. For the purposes of this discussion, the term *federal laboratories* refers to all scientific and engineering laboratories operated under contract by the federal government (GOCOs) or under the direct management of the government (GOGOs). The term *national laboratories* is often used to refer to the Department of Energy's large, multidisciplinary R&D facilities, including weapons laboratories, such as Los Alamos, Lawrence Livermore, and Sandia, and laboratories that focus on basic energy research, such as Argonne, Brookhaven, Lawrence Berkeley, and Oak Ridge National Laboratories. The federally funded research and development centers, operated under contract for the government, span a diverse spectrum from systems engineering and technical assistance, to "think-tank" research organizations.
64. National Science Foundation, *Federal Funds for R&D: Fiscal Years 1989, 1990, 1991* (Washington, D.C.: National Science Foundation, 1991); dollar amount in obligations.
65. Most development of military systems for the Department of Defense is done by private firms, or COCOs, operating outside the laboratory structure. U.S. Congress, House Committee on Small Business, Subcommittee on Regulation, Business Opportunities, and Energy, *Technology Transfer Obstacles in Federal Laboratories: Key Agencies Respond to Subcommittee Survey* (Hearing, March 1990), 7.
66. Defense Science Board, *Technology Base Management* (Washington, D.C.: U.S. Department of Defense, 1987), 13, 22.
67. U.S. Congress, Office of Technology Assessment, *Making Things Better: Competing in Manufacturing* (Washington, D.C.: U.S. Government Printing Office, 1990), 185.
68. NIH Budget Office. Figures are for 1990.
69. P.L. 96-517.

70. P.L. 96-480.
71. P.L. 96-480.
72. P.L. 98-462.
73. P.L. 99-502.
74. Letter from NASA to Representative Ron Wyden, January 12, 1990, p. 2.
75. For a detailed discussion of technology transfer legislation passed during the period 1980-1987 see John S. Wilson, *Productivity and Competitiveness: Industrial Extension Services and Technology Transfer Programs in the U.S.* (Washington, D.C.: The World Bank, 1987).
76. U.S. Department of Energy, *Technology Transfer: A DoE and Industry Partnership for the Future* (U.S. Department of Energy, Washington, D.C., 1991), A-7, A-8.
77. U.S. Congress, House of Representatives, *Technology Transfer Obstacles in Federal Laboratories: Key Agencies Respond to Subcommittee Survey* (Washington, D.C., March 1990), 1-2.
78. U.S. Congress, General Accounting Office, *Diffusing Innovations: Implementing the Technology Transfer Act of 1986* (Washington, D.C.: U.S. Government Printing Office, 1991), 4-5, 11, 106-107.
79. For an interesting general discussion of cultural and other factors in technology R&D, see Ralph E. Gomory, "Technology Development," *Science*, 220 (May 6, 1983):576-580.
80. U.S. Congress, Office of Technology Assessment, *Making Things Better*, 189-190.
81. "Roundtable: New Challenges for the Federal Labs," *Physics Today* (February 1991), 28.
82. Ibid., 29-30.
83. Alan Schriesheim, "Toward a Golden Age of Technology Transfer," *Issues in Science and Technology* 7 (Winter 1990), 54.
84. A 1991 survey conducted by the General Accounting Office found that 685 CRADAs had been completed or drafted by 297 research-oriented federal laboratories.
85. D. Allan Bromley, Director, Office of Science and Technology Policy (Testimony before the Senate Committee on Commerce, Science, and Transportation, Washington, D.C., May 23, 1990), 7.
86. U.S. Congress, General Accounting Office, *Diffusing Innovations: Implementing the Technology Transfer Act of 1986* (Washington, D.C.: U.S. Government Printing Office, 1991), 3-5. Along similar lines, a 1990 report of the House Science, Space, and Technology Committee, for example, found that 61 percent of 180 laboratories surveyed had not received the authority from their agencies to undertake CRADAs, even though four years had passed from the time of the authorizing legislation. Similarly, although the Stevenson-Wydler Act calls for the establishment within each laboratory of a technology transfer office, or Office of Research and Technology Applications, the report found this to be so for only 20 percent of the laboratories examined. U.S. Congress, House of Representatives, Committee on Science, Space, and Technology, Subcommittee on Science, Research, and Technology, "Transfer of Technology from the Federal Laboratories" (Hearing, Washington, D.C., May 3, 1990), 8-9.
87. For an overview of the history of collaborative R&D, see Center for Social and Economic Issues, Industrial Technology Institute, Solomon Associates, and J. D. Eveland, *The Literature of Collaborative Research and Development: An Analytic Overview* (Report submitted to the Office of Technology Assessment, U.S. Congress, Washington, D.C., December 18, 1986).
88. See David C. Mowery, ed., *International Collaborative Ventures in U.S. Manufacturing* (Cambridge, Mass.: Ballinger Publishing Company, 1988); John Hagedoorn and Jos Schakenraad, *Strategic Partnering and Technological Cooperation*, (Maastricht Economic Research Institute on Innovation and Technology, The Netherlands, 1989). For an overview of alliances in the semiconductor industry, see, for example, Carmela Haklisch, *Technical Alliances in the Semiconductor Industry* (New York University, Center for Science and Technology Policy,

1986) and Nicholas S. Vonortas, *The Changing Economic Context: Strategic Alliances Among Multinationals* (Center for Science and Technology Policy, Rensselaer Polytechnic Institute, Troy, New York, 1989).

89. The evidence on whether or not the NCRA has promoted R&D ventures is inconclusive. See U.S. Congress, Congressional Budget Office, *Using R&D Consortia for Commercial Innovation: SEMATECH, X-Ray Lithography, and High-Resolution Systems* (Washington, D.C.: U.S. Government Printing Office, 1990) for a discussion of the NCRA and its impact on the formation of joint ventures.

90. For an overview of SEMATECH, see U.S. Congress, Congressional Budget Office, *Using R&D Consortia*; U.S. Congress, General Accounting Office, *Federal Research: SEMATECH's Efforts to Strengthen the U.S. Semiconductor Industry* (Report to the Committee on Science, Space, and Technology, U.S. House of Representatives, GAO/RECE-90-236, Washington, D.C., September 1990); U.S. Department of Commerce, Advisory Council on Federal Participation in SEMATECH, *SEMATECH 1990* (A Report to the Congress, Washington, D.C., May 1990); and U.S. Congress, General Accounting Office, *Federal Research: SEMATECH's Efforts to Develop and Transfer Manufacturing Technology* (Fact Sheet for the Committee on Science, Space, and Technology, U.S. House of Representatives, GAO/RCED-91-139FS, Washington, D.C., May 1991).

91. Personal communication from Rebecca Racosky, manager for government relations, NCMS, October 3, 1991.

92. Personal communication from Lee Kennard, chief of business integration, Mantech program, Department of the Air Force, U.S. Department of Defense, October 2, 1991. Figures are for FY 1991. In FY 1990, Mantech funding for NMCS totaled $8 million.

93. There have been no independent reviews of NCMS progress in meeting the consortium's objectives. Information available through telephone interviews with NCMS personnel, congressional staff, DOD officials, member companies, and other R&D organizations, presents a mixed assessment of progress to date at NCMS. Apparently, small manufacturers that typify the U.S. machine-tool industry delegate only limited staff resources to tasks associated with NCMS projects. NCMS, like other collaborative R&D ventures, continually works to balance the desires of member companies to target research to specific company needs, against the goal of producing and disseminating R&D results useful to other member firms. Indeed, officials of several member companies contacted for information about NCMS report benefits from NCMS projects to in-house R&D objectives. They cite especially the leveraging of internal R&D resources in projects in support of manufacturing technology, such as a computer-integrated factory, next-generation controllers, and improved manufacturing techniques for fabrication of printed wiring boards.

94. For an overview of the ERC program, see National Science Foundation and American Association of Engineering Societies, *The ERCs: A Partnership for Competitiveness*, Report of a Symposium (Engineering Centers Division, Directorate for Engineering, National Science Foundation, Washington, D.C., March 1990); and National Academy of Engineering, *Assessment of the National Science Foundation's Engineering Research Centers Program* (Washington, D.C.: National Academy of Engineering, 1989).

95. See, for example, Barry Bozeman, Albert N. Link, and A. Zardkoohi, "An Economic Analysis of Joint R&D Ventures," *Managerial and Decision Economics* 7 (1986):263-266, as cited in David C. Mowery, "Collaborative Research: An Assessment of Its Potential Role in the Development of High Temperature Superconductivity (Report prepared for the Office of Technology Assessment, U.S. Congress, Washington, D.C., 1988), 4.

96. See, Richard J. Samuels, *Research Collaboration in Japan* (Massachusetts Institute of Technology, Cambridge, Mass., 1987), 36; and U.S. Congress, Office of Technology Assessment, *Making Things Better*.

97. For a discussion of the ERA system and its history in Japan, see Samuels, *Research Collaboration in Japan*.

98. Jonah D. Levy and Richard J. Samuels, *The MIT Japan Program* (Paper prepared for the Conference on Oligopolies and Hierarchies: Strategic Partnerships and International Competition, Fondation de Royaumont, Asnière-sur-Oise, France, April 20-23, 1989. Available from Center for International Studies, MIT, Cambridge, Mass.), 32.

99. Fumio Kodama, "Rival's Participating in Collective Research: Its Economic and Technological Rationale" (Paper presented to the NISTEP International Conference on Science and Technology Policy Research, Shimoda, Japan, February 2-4, 1990), 8-9.

100. See Richard R. Nelson, *High-Technology Policies: A Five Nation Comparison* (Washington, D.C.: American Enterprise Institute, 1984), 48-50.

101. For an overview of collaborative R&D in Japan see reports of the National Research Council, Office of Japan Affairs, including *R&D Consortia and U.S.-Japan Collaboration: Report of a Workshop* (Washington, D.C.: National Academy Press, 1991).

102. This section draws on interviews conducted in Tsukuba, Science City, Japan in July 1990 by the project director. Included in the discussions were officials of the Optoelectronic Technology Research Corporation and Optoelectronics Technology Research Laboratory. See also *The Japan Key Technology Center*, Program Prospectus (Tokyo, Japan, 1989), and *Key Technology for the 21st Century*, Program Description (Optoelectronics Technology Research Laboratory, Tsukuba, Science City, Japan, 1990).

103. Interview by John S. Wilson, National Academy of Sciences, with Takeshi Furutani, Deputy Director, Electronics Policy Division, Ministry of International Trade and Industry and other MITI staff, Tokyo, Japan, July 1990. For an overview of resources devoted to research and development in Japan through Japan fiscal year 1987, see *1988 Survey of Research and Development in Japan*, January 11, 1989, National Science Foundation, Tokyo Office, Tokyo, Japan. See also National Science Foundation, Tokyo Office, *JFY 1988 R&D Budget of Japan's Ministry of International Trade and Industry (MITI)* (Tokyo, Japan, 1989) for a description of MITI projects in basic R&D.

104. G. J. Hane, *Government-Promoted Collective Research and Development in Japan —Analyses of the Organization Through Case Studies* (Washington, D.C.: Pacific Northwest Laboratory, Battelle Memorial Institute, 1990), 2-5.

105. Data provided by the Japan Key Technology Center, Ark Mori Building, Akasaka, Minato-ku, Tokyo, Japan.

106. Interview with Izui Hayashi, Director, Optoelectronics Technology Research Laboratory, Tokyo, Japan, by John S. Wilson, National Academy of Sciences, July 1990.

107. See, for example, National Research Council, *Learning the R&D System: Industrial R&D in Japan and the United States* (Washington, D.C.: National Academy Press, 1990).

108. For an overview of U.S. and Japanese spending on R&D and technology development, see National Science Foundation, *The Science and Technology Resources of Japan: A Comparison with the United States*, NSF 88-318 (National Science Foundation, Washington, D.C., 1988).

109. See Mowery and Rosenberg, *Technology and the Pursuit of Economic Growth*, 227.

110. Roy Rothwell and Mark Dodgson, "Technology Policy in Europe: Trends and Impacts," in *Science, Technology, and Free Trade*, eds. J. de la Mothe and L. M. Ducharme (London: Pintner Publishers, 1990).

111. *Official Journal of the European Communities*, Council Decision of April 23, 1990, no. L 117/28.

112. Delegation of the Commission of the European Communities, *Important Progress for European Community Research* (May 18, 1990), 1.

113. An evaluation of ESPRIT appears in John A. Alic, *Cooperation in R&D* (Paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, D.C., 1988).

114. Rothwell and Dodgson, "Technology Policy in Europe," 2.

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126. For an overview of state technology extension services, see Robert E. Chapman, Marianne K. Clark, and Eric Dobson, National Institute of Standards and Technology, U.S. Department of Commerce, *Technology-Based Economic Development: A Study of State and Federal Technical Extension Services*, NIST Special Publication 786 (Washington, D.C.: U.S. Government Printing Office, June 1990).

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129. *Procedures for the Selection and Establishment of NIST Manufacturing Technology Centers*, Part 290, Title 15 of the Code of Federal Regulations, as published in the *Federal Register* (September 17, 1990), 8.

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131. Letter of Samuel Krammer, Chairman MTC Review Panel to Dr. John W. Lyons, Director, National Institute of Standards and Technology, September 19, 1991. For additional information on the MTC program, see National Institute of Standards and Technology, *The Manufacturing Technology Centers Program: A Report to the Secretary of Commerce by Visiting Committee on Advanced Technology* (Gaithersburg, Md.: NIST, 1990).

132. Source: U.S. Department of Commerce, National Institute of Standards and Technology.

133. Source: U.S. Department of Commerce. Figures are for funds appropriated for grants in FY 1991.

134. There is evidence, however, that extension activities have conflicted with the demands of topflight scientific research. The decentralized, extensive, and "user-friendly" structure of the agricultural research and extension services has made it difficult for federal policymakers to redirect and improve the quality of agricultural research, especially in cutting-edge areas such as biotechnology. An integrated research and extension organization in agriculture may have important costs, therefore, as well as some important advantages.

135. Mowery, "The Diffusion of New Manufacturing Technologies," 498.

136. See Gerald P. Dineen, "Trends in International Technological Cooperation," in *Globalization of Technology: International Perspectives* , Proceedings from the Sixth Convocation of the Council of Academies of Engineering and Technological Sciences (Washington, D.C.: National Academy Press, 1988).

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3

A New Strategy to Facilitate Government Support of Technology

This report has examined the changing environment for research and technology development, with particular emphasis on the role and responsibility of the federal government in R&D and technology policy. In addition, the previous chapters provide an assessment of the strengths and weaknesses in current federal programs to assist industry in civilian technology development, transfer, and adoption.

As we have seen, the economic and technological environment in which private firms develop and commercialize new technologies has been altered in a fundamental manner since World War II. Over the past 25 years, the world economy has changed dramatically. It is characterized by improved communication systems, the international flow of capital and trade, the rapid diffusion of information and technology across national borders, and advances in technology utilization. All of these factors have improved the capacities of firms outside the United States to commercialize products and services.

The United States continues to exhibit great strength in technology, especially in the generation of new and innovative products and processes. U.S. performance in technology commercialization, however, is being challenged more strongly than ever before as a result of improvements in the capabilities of foreign firms. We believe, therefore, that the federal government needs to promote a higher rate of technological performance in the United States. We should build on the nation's strengths in research and advanced technology. It is sensible and appropriate to capitalize on U.S.

comparative advantages in technology creation, much of which has been built through federal support, to strengthen private sector capacities.

Current government programs that support and finance pre-commercial R&D, although in certain cases adequate to meet the past needs of private sector technology efforts, are inadequate to meet the nation's needs in today's competitive environment in key technology areas. Incentives can be provided by the government to achieve higher rates of technology commercialization in the private sector over the long-term. A new federal role in pre-commercial R&D is necessary, and in the panel's judgment, the U.S. government is capable of executing this mission. It has proved effective in stimulating technology commercialization in the civil sector in the past.

As outlined in Chapter 2, the U.S. government played an important role in facilitating investment, stimulating R&D and technology generation, and promoting technology adoption in sectors such as commercial aerospace, agriculture, energy, and health care. By financial support for investment in pre-commercial R&D and technology adoption, the federal government, in many instances through public-private cooperative ventures, provided support beyond funding of basic science. Federal agencies, such as the Department of Agriculture, National Institutes of Health, Department of Defense, and National Advisory Committee for Aeronautics contributed to technology commercialization and the adoption of new technology in private firms. Indeed, in aircraft, high-performance computers, and agriculture, the federal government had a direct role in the creation of industries that today dominate world commerce and generate export surpluses for the United States.

Although the government has assumed a direct role in civilian technology in the past, the current framework that defines the federal role in technology is weak in several respects. It is characterized by the underfunding of pre-commercial R&D and technology adoption projects, and by a political process that determines, to a great extent, those projects that are to be funded in pre-commercial R&D. In addition, we believe a reliance on broad tax measures to stimulate investment in R&D, although helpful, is insufficient in the absence of other measures to meet the needs of improving U.S. performance in technology.

The justification for federal investment in basic research rests on the fact that the private market fails and that the returns to private firms from investment in basic research are insufficient to induce them to fund it from society's perspective. Market failure is also evident, however, in the stages of technology development that lie "downstream" from basic research and are closer to technology application. Basic research rarely yields results that can be translated swiftly and at low cost into commercial technologies. As noted in Chapter 1, investments are often needed in pre-commercial R&D to improve understanding, explore applications, and evaluate designs. The federal government should participate in this activity.

The federal government should invest in the pre-commercial area of R&D between basic research and narrow, focused commercial application.[1] Pre-commercial technology often involves a probability of success too low for a commercial venture to risk. The appropriability gap stems, in part, from the difficulties associated with refining technology development and inventions for new concepts to make them manufacturable and to incorporate innovations into products. The problem of "nonappropriability," which has long been accepted as a rationale for public support of basic research, also applies to the transfer and utilization of new scientific or technological information. Much of the organization of R&D in industry is influenced by the costs and complexities of technology transfer and utilization. Public support for technology, therefore, should include a role in supporting its utilization and diffusion, as well as the creation of technological knowledge.

It is important to note that an expanded role for the federal government in funding of pre-commercial R&D should focus only on technologies that the private sector would not develop on its own. An expanded role for government should center on R&D and technology development projects whose size, scope, or expected return on investment falls outside what a venture capital firm might fund. We do not believe that the federal role in civilian technology should extend to funding R&D projects that are sufficiently viable technically and economically to attract capital funding in private markets (venture capital).

The United States has a strong venture capital industry that has supported investments in high-technology firms with near-to-market commercial technologies. Venture capital firms do not, however, make investments in or provide assistance for R&D in areas where there are ill-defined potential markets. This is true even if strong, economy-wide potential applications for the technology exist. Venture capital firms also do not fund technology development projects where it is unlikely that the economic benefits of innovation are appropriable to the firm. Moreover, these firms seek an average annual return on capital of 20 percent or more. An expanded federal role in R&D, therefore, would not compete with venture capital firms, but rather would center on projects with widely applicable "generic" technologies that do not involve firm-specific incentives or the commercial needs of an individual firm.

The process by which initiatives in pre-commercial R&D and technology are proposed and funded by the federal government also requires reassessment and improvement. Federal financial support for R&D and technology is not coordinated; indeed, it does not exist in a manner that would allow selection of investments in areas of high risk and high potential payback to support U.S. comparative advantages. At the same time, there are indications that support for civilian R&D and technology development will continue to be proposed by industry groups and established largely through a political process that is seriously flawed.

The political process through which pre-commercial programs are often initiated is not the most efficient and equitable method of allocating federal resources or building new government programs. This is true even when considering the potential future merits of these projects. There will most likely be increasing pressure for the U.S. government to make investment decisions on funding for R&D in a wide range of technology areas. Some of these projects may be beneficial to the nation's comparative advantage and leverage its technological strengths.

Tax incentives for R&D are often mentioned as a preferred method of promoting higher levels of industrial R&D activity in the United States. The Economic Recovery Tax Act of 1981 (P.L. 97–34) provided an initial 25 percent credit for incremental increases in corporate R&D spending. The law was later amended in the Tax Reform Act of 1986 to reduce the credit to 20 percent and revised again to include start-up ventures in the Budget Reconciliation Act of 1989.[2] The credit for R&D is set to expire in June 1992.

There remains some uncertainty over the precise effect of R&D tax credits on spending for research in industry.[3] There is, however, likely some benefits associated with tax credits for R&D investments as well as costs associated with any tax credit that lowers federal revenue, particularly for firms in high-technology sectors with large and growing R&D budgets (as a percentage of sales) over a number of years. Higher levels of private investment should follow the lowering of any tax, including lower costs to firms anticipating R&D tax credits in future years.[4] One assessment of increased corporate R&D spending as a result of the credit indicated that in 1989, for example, $701 million more was spent on R&D in the United States.[5]

Although there are potential long-term benefits to R&D tax credits, we believe that these credits alone are insufficient to achieve the objective of higher overall rates of technological performance in the United States. Because R&D tax credits have not been made a permanent part of U.S. tax law, businesses are unable to plan their R&D investments with certainty. The credit may be extended or terminated every few years. Another problem with the R&D tax credit is that incentives are not available to all firms engaged in R&D activity. For example, under the law, no credit is given if current R&D spending is below a calculated base-level average over a four-year period. In addition, the possibility of selecting socially beneficial projects in pre-commercial areas is absent in measures such as the R&D tax credit.

The panel does not advocate targeting specific sectors or firms for special government financial subsidies. The United States, however, needs a mechanism to bring a higher degree of specificity than tax policy changes can induce to channel R&D resources to socially beneficial projects and to allocate funds under a new federal role in technology that is outlined in this report. Simply stated, tax or regulatory changes to promote commercialization lack selectivity. They are—whatever their general merit—a blunt policy tool. Finally, improvements in macroeconomic conditions, such as further reductions in the federal budget deficit or other measures to reduce federal dissavings and promote investment—although probably crucial in improving the long-term competitiveness of U.S. industry—will do little over the next decade to enhance pre-commercial R&D investments and technology commercialization efforts by U.S. firms.

A frequent and serious objection to government involvement in private sector R&D or technology commercialization efforts is that government should avoid promoting one technology area, industry sector, or individual firm over another. It is well established that private markets perform best in allocating resources and "selecting winners" in the commercial marketplace. Political pressures in a constituent-oriented democracy tend to favor losers, not winners. To a great extent, decisions on whether to engage in particular fields of commercial development should be the domain of industry. The panel believes that this framework for decision making has substantial validity when considering R&D investments far downstream of basic research and ones that center on choices for product development in the civilian sector.

The objections to government direction of private sector activity are especially valid when technology policy is reflected in programs that provide subsidies to specific industries or firms. Some industrialized nations employ a wide range of technology and trade policy tools to ensure domestic capacities in high-technology industries. There are significant costs associated with direct subsidization by governments for "research and development" work on applied R&D in specific industry sectors or when markets are closed to international competition to protect domestic producers. Strong, continuing political pressures from special interest groups, especially in the United States but also in other nations, encourage direct government subsidies to industries that are not competitive in global markets. The United States can construct a technology policy that avoids industrial policy and does not protect industries and firms. We can accomplish this while, at the same time, supporting and leveraging U.S. comparative advantages in technological innovation. Although the innovative capacity of the United States remains strong, we believe that the ability of U.S. firms and citizens to capture the benefits of innovation may have declined over the past several decades. The federal government's focus in technology policy should be altered from one that emphasizes support for basic research to one that includes incentives for pre-commercial R&D and the adoption of new technologies.

Based on an assessment of past government intervention in private markets and the changed technological environment, it is reasonable to conclude that the government can, under certain circumstances, act as a catalyst in promoting private sector R&D. This is particularly true as it relates to funding of pre-commercial R&D in partnership with industry through collaborative projects. The government can provide financial support for R&D efforts judged promising by industrial firms and technologists by making investments that will benefit U.S. industrial performance and enhance long-term productivity growth and the welfare of U.S. citizens.

An important reason for the success of the Defense Advanced Research Projects Agency (DARPA) and the National Advisory Committee on Aeronautics, in several areas, was their clear-cut mission (development of advanced dual-use and military technologies and of civil aeronautic technologies, respectively). Support for civilian technology is a more difficult task than supporting specific technologies for which the government is the funder, the customer, and the end user.[6] An obstacle for new federal initiatives in pre-commercial technology is the lack of a well-defined focus that links to end users provide. This complicates priority setting and decision making about funding.

The panel believes, however, that federal investment in pre-commercial R&D can be effective if the guidelines detailed below are followed closely. Investments in infrastructure-related technologies or facilities for new manufacturing technologies with wide industrial applications, for example, have the potential to generate significant public returns to federal investment and can stimulate productivity and long-term economic growth.

As outlined in Chapter 2, current efforts by mission agencies to stimulate R&D and technology may be useful in specific cases. They are inadequate, however, to meet the objective of strengthening government-industry cooperation in R&D and pre-commercial technology. This is true for programs such as the Advanced Technology Program at its likely future level of funding. Mission agency funding of R&D of this nature is neither sufficiently broad in its coverage of fields nor, in most instances, at the necessary level of continuing funding to affect technology commercialization efforts in a substantial manner.

An expanded government role in cooperation with the private sector is inevitable for several reasons. First, recent experience suggests that the government will continue to finance R&D in pre-commercial areas. Concerns about national security, economic growth, and the behavior of foreign governments have provided the motivation for these projects. Several initiatives in pre-commercial R&D have been established as much through political pressure and private sector special interest lobbying as for their potential technical merit. A more rational, balanced, and organized method for the government to respond to such initiatives is needed.

Second, as outlined in Chapters 1 and 2, heightened international competition and the strength of our competitors' technological competence will drive costs and risks of investment in pre-commercial R&D higher. In some cases, these costs and risks are beyond the ability of individual firms or groups of firms engaged in R&D programs. For cases in which there are high expected social benefits, large externalities and spillovers in other sectors, and appropriability problems for private firms, these costs will fuel pressure for federal action.

Finally, there is the growing dependence of U.S. jobs and living standard on international trade. This makes investments in pre-commercial R&D and technology, which may lead to commercializable products and processes, more important today than in the past. The growth of U.S. exports over the past several years, especially the success of many high-technology capital goods producers and service sector companies (which rely on continued advances in R&D) in international markets should be built upon by leveraging the nation's strengths. One way to do this is to facilitate pre-commercial R&D. Government moves to fund pre-commercial R&D, as evidenced in the establishment of the Advanced Technology Program, the Semiconductor Manufacturing Technology Research Corporation (SEMATECH), the National Center for Manufacturing Sciences (NCMS), and other federally sponsored R&D organizations, are in part a result of these factors. The panel believes such a move is appropriate. The challenge, therefore, is to design a framework for ensuring that the federal government's technology policy operates in the most rational and effective manner.

This chapter outlines options for shaping a new federal role in pre-commercial R&D and technology. Extending federal support for pre-commercial R&D is only one of a range of policy tools that may enhance technology as a U.S. comparative advantage. Many factors contribute to technological innovation, including skill enhancement of the work force, stability of global macroeconomic environment, and public and private rates of savings. Although we do not provide a comprehensive set of recommendations to bolster U.S. competitiveness, the panel does offer a focused set of options to affect U.S. performance in technology, the subject of the academies' request from Congress for this report.

This chapter outlines several important methods to strengthen U.S. technology policy and complements the recommendations on the establishment of an Industrial Extension Service at the Department of Commerce, the reinforcement of DARPA's role in dual-use technology, and recommendations on reforming policy on technology transfer from the federal laboratories found in Chapter 2.

In this chapter we consider the expansion of mission agency support for pre-commercial R&D, as well as the possibility of two new organizations, a

Civilian Technology Agency (CTA) and a quasi-governmental Civilian Technology Corporation (CTC). Both the CTA and the CTC might, in theory, be established to provide financial assistance to firms for pre-commercial R&D.

The advantages and disadvantages of each of these options is outlined below. Although an agency within the federal government, such as the CTA, may have some merit, the panel has concluded that this approach has significant drawbacks. Establishment of a CTC is the preferred option. This chapter will also provide general principles under which any plan to formalize government-industry cooperation should proceed. The guidelines for organizing and rationalizing the process through which federal investment in R&D is undertaken can help ensure a more efficient and rational approach to federal investments in pre-commercial areas.

GUIDING PRINCIPLES

The congressional request for this report included the mandate to recommend methods to strengthen government-industry cooperation in civilian technology. In particular, the law directed the academies to examine ways in which R&D cooperation might be structured to enhance the technological performance of U.S. industry. The following guidelines present an important framework for Congress and the executive branch as they design future cooperative ventures between government and industry and modify existing programs.

There is a long history of federal involvement in cooperative R&D and civilian technology development, as noted in Chapter 2.[7] In particular, over the past two decades, Congress and the President have attempted to stimulate commercially relevant R&D through the establishment of a variety of initiatives. Examples of this include the formation of inter-agency working groups on civilian technology development and cooperative R&D, a proposal to the create a Civilian Industrial Technology Program (under the Kennedy administration), and the New Technological Opportunities program (under the Nixon administration) designed to stimulate private sector R&D in areas where market forces were inadequate to foster investment. The Industrial Innovation Initiatives program, announced in 1979 by President Carter, was aimed at both support for university-industry cooperative R&D and support for generic, applied R&D through government-industry cooperative R&D projects. During the Reagan administration, SEMATECH, the NCMS, and other publicly funded joint ventures were established. Many of these programs were established in response to concern over the defense industrial base, although much of the work in these programs may also have beneficial impacts on civilian technology development. One factor that limited the potential for success in several of these agency-sponsored efforts (at least those proposed or established prior to the 1980s) in pre-commercial R&D is that they lacked guidelines on a common framework and rationale for organizing federal investments and financial support. To provide the analytical framework for any future government initiatives in this area, the panel has developed a set of guidelines that should be followed.

Each of the specific options reviewed by the panel for supporting pre-commercial R&D could, in theory, serve to strengthen U.S. comparative advantages in global markets. There are methods that can build on the driving forces of competition operating in a market-oriented economy and help to ensure that R&D investments will be made while minimizing the damaging influences of political or special interest group manipulation of federal programs. These guidelines, in part, serve to meet this important objective. Whichever mechanism is eventually adopted by the federal government, the operational guidelines to be followed in each option should be consistent with the following principles to ensure effective administration of financial assistance in R&D and technology.

Principle 1: Cost Sharing

A primary goal of any federal program that provides financial assistance to private firms should be to ensure that public funds are used to leverage corporate strengths in technology. The government should not attempt to override private market signals on the direction of development of promising technologies. Direct and unmatched government subsidies or grants to private firms for R&D or technology development projects can redirect scarce resources, both financial and human, into unproductive channels. To ensure the market relevance of R&D funded by the government in cooperative ventures, participating private sector firms or institutions (except nonprofit organizations) should bear a significant share of program costs. In most cases, this would involve private firms covering on the order of 50 percent of the total program costs of any pre-commercial R&D or technology project.

There are several reasons why cost sharing is important. Cost sharing helps provide the private market incentives necessary for efficient allocation of scarce federal and private resources. It also ensures that projects undertaken match, as closely as practical, commercially relevant R&D.[8] Federal efforts to support technology development clearly show the impact of cost sharing on private sector participation in joint R&D programs. There are many examples of federal experiments in R&D and technology that have lacked provisions on cost sharing. Most have been less than successful due to this deficiency in program design. Lack of a link to market-oriented incentives, established when a firm risks its own financial resources, leads to suboptimal performance. This fact was particularly apparent in the Department of Energy's (DOE) attempt to develop alternative energy demonstration programs during the late 1970s.

There were many problems associated with DOE efforts in renewable and alternative energy R&D. One reason that attempts to support new energy technologies were less than successful was that the government assumed all costs associated with the R&D projects. A strong link to private sector R&D agendas and commercial markets was missing. These and other initiatives demonstrate that in order to avoid subsidizing technologies with little chance of success in the commercial marketplace, federal programs must include cost sharing.

A legitimate concern is whether cost-sharing arrangements will merely subsidize industry's lower-priority technology development projects. There is that risk. The provision of a stable, multiyear federal contribution, as well as collaboration between several firms under federal sponsorship, however, should encourage longer-range projects that now tend to suffer from the short-term horizons of corporate management.

Cost-sharing requirements strengthen the link between R&D and commercial applications. Several federal R&D programs now include cost-sharing provisions: Cooperative Research and Development Agreements between federal laboratories and industry; the Commerce Department's Advanced Technology Program (ATP); and the Small Business Innovation Research (SBIR) program, administered by the Small Business Administration, for example.

Principle 2: Industry Involvement in Project Initiation and Design

The long-term objective of extending the government's financial commitment to pre-commercial R&D is to enhance U.S. productivity and raise its standard of living. To do this, support for R&D should be closely linked to commercial markets, as well as being in areas with the potential for wide industrial application. Projects to stimulate collaborative R&D ventures funded through government-industry partnerships should be proposed and structured by industry. The private sector should be responsible for technical designs and the building of research agendas in any expanded federal program in pre-commercial R&D. SEMATECH and the National Center for Manufacturing Sciences, for example, were created in large part due to industry-led efforts to initiate the projects and to design the research frameworks. To the extent that these efforts are successful, early private sector proposals for technical design of the R&D work and control over the projects will have helped to ensure that success.

Allowing private market signals to act as the signal for government action increases the possibility of success in high-risk R&D projects. Industry is in close contact with private markets, much more so than govern ment. Private industry should be relied on for its judgment and expertise in these matters. Industry initiation and design of research programs and of the framework for R&D collaborative ventures will help government avoid directing product and process technology development.

Principle 3: Insulation from Political Concerns

The choice of R&D projects under an expanded federal program to support pre-commercial ventures should be based on technical and economic assessments of the merits of a specific R&D program. Evaluations of competing R&D proposals—either by a single firm or by groups of firms in a collaborative venture—that might be sponsored under an expanded federal program should be conducted by independent experts in the relevant scientific, technological, and economic areas. Political considerations should not influence R&D programs' technical output, the location of R&D facilities, or the management of R&D projects. Although this is a generally desirable goal, the complete removal of political factors from decisions on R&D investments is unlikely in most situations. The danger of close connection between R&D agendas and political concerns is real. Efforts should be made to avoid special interest politics in these programs.

Pressures from special interest groups working through the political process can result in at least three less-than-optimal outcomes in federal decision making on investments in R&D. First, funding or site selection can be targeted to help local political constituents, regional interests, or agency bureaucracies. Second, research and development programs work best under conditions of relative autonomy and long-term funding commitments. Intervention by the political process—which repeatedly seeks to micromanage R&D projects—is potentially disruptive and costly. Finally, support based on political as opposed to technical considerations is likely to lead to wasteful, open-ended subsidies of inefficient, uncompetitive firms and industries.

Principle 4: Diversification of Investments

Projects funded under an expanded federal program should complement and not compete or interfere with pre-commercial R&D and technology development activities under way elsewhere in the federal government. This is especially true in programs that have been successful in meeting mission requirements or that currently have close technology links with the commercial marketplace. Examples include work at the National Institutes of Health in biomedical R&D and biotechnology, at the National Institute of Standards and Technology (NIST) in advanced manufacturing techniques and automated manufacturing technologies, and at the Department of Ener gy in combustion engineering R&D. Pre-commercial R&D programs can address deficiencies in the commercial marketplace in technologies with the potential for widespread industry application and long-term significance to the U.S. economy.

The decentralized nature of most government technology programs, which can serve to diversify federal investment in R&D, also increases the likelihood that uncoordinated programs will duplicate activities already under way in other federal agencies. In some cases, duplication of pre-commercial R&D projects is beneficial. Projects funded in a new program should not, however, duplicate related programs, particularly in the applied, mission-related R&D projects under way in federal agencies.

Diversification across projects by technology area is also essential to the success of an expanded federal program. A broad portfolio of investments in technical fields, including the biomedical sciences and biotechnology, materials sciences, manufacturing product and process technologies, and computer and telecommunications-related technologies, should help ensure that an expanded government role in pre-commercial R&D does not become captive to the interests of a particular technology champion or a set of companies.

Principle 5: Projects Open to Foreign Firms Characterized by Substantial Contribution to U.S. Gross Domestic Product (GDP)

Collaborative projects in pre-commercial R&D supported by the government under an expanded federal program should be open to foreign firms that contribute in a substantial manner to the U.S. gross domestic product (GDP). Barriers to foreign participation in U.S. government-funded cooperative R&D projects have recently been put in place. Foreign participation is restricted in collaborative R&D projects sponsored by NIST's Advanced Technology Program, as well as those undertaken by the National Center for Manufacturing Sciences, and SEMATECH, for example.[9] In most instances where restrictions have been put in place, a U.S. firm is defined as one under the control of U.S. citizens or incorporated in the United States. In a few cases, such as the ATP program, foreign firms may participate if the project under consideration would enhance U.S. competitiveness over the long-term more than if foreign firms were excluded.

In an interconnected global economy where goods and services flow rapidly across national boundaries, the U.S. government should seek to ensure that technology and production capability of the most up-to-date and competitive kind flows to U.S.-based development and manufacturing facilities. There are significant benefits that accrue to the U.S. economy through the training, education, and skill enhancement offered by foreign-based corporations with U.S. affiliates. Many of the foreign-owned corporations located in the United States provide for an improved quality of the U.S. work force, and contribute to U.S. economic growth and standards of living. To help ensure that these benefits flow to the U.S. economy, however, a movement toward open access to programs overseas for U.S.corporations, scientists, and engineers is required.

There are long-term economic costs associated with any form of restriction on foreign participation in national economic systems. These costs should be recognized and acknowledged. Public policies that attempt to strengthen U.S. competitive advantages in technology through the closing of domestic markets to foreign goods and services, limits on technology flows, or restricting foreign participation in government technology programs are potentially damaging to long-term U.S. economic interests. Limitations on foreign participation in cooperative R&D projects can isolate the U.S. economy from scientific and technological advances made in other industrialized nations. Public policies should not only encourage U.S. industry to draw on technology from overseas to improve the national base, but should also help leverage the technology available in "foreign" firms that contribute to the national welfare.

As we have shown in Chapter 1, foreign capacities to generate and commercialize technologies are rapidly advancing. We should no longer expect to rely only on technological advances generated by firms incorporated in the United States. Moreover, many of the most competitive, high-technology U.S. firms have extensive R&D, manufacturing, and other cooperative agreements already in place with foreign firms. Collaborative ventures and technology links with foreign companies can play an important part in these firms' competitive strategies. Cooperation in R&D can reduce innovation costs and time to market for products, enhance the technological competence of member firms, and allow ongoing monitoring of advances in science and technology in specific fields.

Decisions about foreign participation in U.S. scientific and technological endeavors, whether in cooperative projects at the national laboratories, government-supported consortia, or university R&D activities, should be framed with clear recognition of the benefits of collaboration between U.S. and foreign firms. Access to advances by Japanese and European firms in such areas as advanced ceramics and semiconductor manufacturing technologies (wafer fabrication, steppers), among others, can benefit U.S. firms and strengthen domestic technological capabilities.

In addition, some of the most successful U.S.-owned multinational corporations operate large facilities overseas; these may be placed at a disadvantage through restrictions put in place by foreign governments on access to their government-funded R&D projects. The United States should take the lead in making access to cooperative R&D projects more open in the international context. Lack of complete symmetry in access to programs overseas, however, should not block steady progress toward opening U.S. R&D ventures to the participation of firms that contribute in a substantial manner to the economic vitality of the United States.

Therefore, expanded programs to finance pre-commercial R&D should not be closed to the participation of foreign firms that are characterized by substantial contributions to the U.S. GDP. In many cases, participation in these projects would require eligible firms to have extensive R&D, manufacturing, and processing operations within U.S. borders, even when they are neither under the direction of U.S. citizens nor incorporated as independent businesses in the United States. Finally, U.S. government funds provided for pre-commercial R&D would be expended on projects undertaken predominantly in the United States.

Principle 6: Program Evaluation

Rigorous technical and economic evaluation is an essential part of any technology program, especially of efforts to extend federal support for pre-commercial R&D. An independent evaluation of each project should be undertaken approximately five years after an R&D project is initiated. A review of program performance conducted for Congress and the President, under the following options, should be undertaken by a qualified group of experts, including those with technical, managerial, and economic experience. An overall evaluation of the mechanism chosen for any further substantial federal investment in pre-commercial R&D would be appropriate after 10 years.

Current efforts to review government R&D programs have suffered, in some instances, from the fact that annual reports to Congress or the executive branch have been conducted by mission agency employees with an direct interest in having projects they evaluate continue. Technical evaluations of the R&D work and of the contributions to national economic welfare of pre-commercial R&D programs should be conducted by nongovernmental groups that do not have a direct role in program management or funding decisions.

The review proposed for an extended federal program in pre-commercial R&D should be conducted by an independent panel of experts, nominated by the President and confirmed by the Senate. The panel should include a wide range of individuals with both technical and economic expertise to ensure that it represents, to the extent practical, knowledgeable and disinterested reviewers. Admittedly, it is difficult to identify review panels that are composed entirely of disinterested and knowledgeable experts. Such panels can, however, be formed with a careful, rigorous adherence to balance and the transparency of potential conflict and bias.

This type of review would not only evaluate the efficacy of the R&D

project or institutional mechanism (expanded agency programs, a CTA, or a CTC) but also include a thorough review of the specific projects undertaken by the overall program. Reviews would include an analysis of the balance between financial support for technology creation and enhanced rates of technology adoption in U.S. firms. If the original objectives set forth under a joint R&D venture sponsored with federal financial assistance are reached or the results of a program are insufficient to justify the resources expended, programs should be terminated. Federal agency authorities and Congress should, as a matter of policy, follow recommendations by the review panel, either to terminate or to extend a project.

FACILITATING FEDERAL INVESTMENT IN TECHNOLOGY

This section considers several options to support extension of the federal government's role in technology and to strengthen government-industry cooperation in pre-commercial R&D. As noted in preceding chapters, the primary goal of U.S. technology policy is to provide the basis for increases in productivity growth and higher standards of living. We have concluded that, to support private sector efforts that drive this process, the U.S. government should move beyond its primary focus on investments in basic research, with a better balance among support for technology creation, pre-commercial R&D work, and technology adoption. The government should act as a catalyst to stimulate investment in pre-commercial R&D that benefits the national economic welfare. In each of the options outlined in the following pages, financial support by the government would be aimed at high-risk, high-potential projects in R&D. The objective of such a program would be to increase the rate and speed at which new technologies diffuse throughout the economy.

Expanded Mission Agency Funding of Pre-Commercial R&D

The first alternative considered for an expanded federal role in financial support for pre-commercial R&D is a decentralized, multiagency approach to project funding. Although federal agencies currently fund work in pre-commercial areas, these efforts are at a level of funding and scope that limits their impact on commercial markets. Additional financial resources would be provided to several federal agencies under new programs housed in agencies with missions related to important sectors of the economy. These agencies include the Department of Agriculture, the Departments of Defense (DARPA) and Energy, and the National Institutes of Health.

As noted in earlier sections of this report, the majority of *federal* R&D funding (which constitutes approximately 50 percent of total *national* R&D spending) is defense related. It is channeled to basic scientific research or to defense research projects conducted in U.S. universities, mission-oriented national laboratories, and federally funded research and development centers (FFRDCs). Many of these are operated by civil servants or are under government contract.

A new federal program to extend mission agency R&D would involve a major, multiprogram effort by only a *few* federal agencies, which would devote funding and personnel to programs aimed at collaborative R&D with private firms. We do not consider this option to include an across-the-board increase in all federal agency R&D budgets. Additional funds might, in a few cases, be appropriated by Congress specifically for this mission, although in other instances, resources might be reallocated from other programs to meet the objective.

This option has several advantages. For example, it would be relatively simple to implement through agency programs that either are already in operation or could be quickly set in place. Expanding the current scope of a few agencies' missions in R&D into pre-commercial areas would also provide support for technology efforts in organizations that are presumed to understand the needs of their constituencies (agencies with at least some indirect link to commercial markets through mission-specific procurement and/or laboratory networks). Several agencies, such as DARPA and the National Institutes of Health, have had some success in supporting technology development in the past. DARPA, in particular, should play a central role in fulfilling this mission, as discussed below.

One disadvantage to this approach is that available resources would be scattered across several agencies. Moreover, project sponsorship would not include attempts to identify technologies of potential long-term significance to U.S. economic growth. Priorities would most likely correspond to agency objectives, and there is the likelihood that departmental programs would not be complementary. New programs would compete for funds with existing and well-established agency functions.

Many agencies have strong constituencies in place. The likelihood that narrow, industry-specific constituencies would endorse this option suggests that political considerations might determine the allocation of program funding. Expanded mission agency funding for pre-commercial R&D within present agency structures would also have to follow government procurement rules and civil service guidelines. The panel believes that this system, which is in operation now in many technology transfer and development programs administered by the government, has had only limited success. It does not promote administrative efficiency or program flexibility, two necessary though not sufficient conditions for a new strategy to foster commercial R&D.

After consideration of the advantages and disadvantages of extending program authority and the provision of additional financial resources to mission

agencies, the panel has concluded that this option deserves consideration only on a very selective basis. It should be undertaken only at agencies that have had success in selected programs aimed at promoting commercial technology development efforts in the past. This might include, for example, DARPA, the Department of Energy's support for energy research, and the National Institutes of Health.

A program such as the one outlined above is appropriate. If the federal government pursues this strategy in the absence of other initiatives, however, it will be inadequate to meet national objectives. Government programs to encourage pre-commercial R&D and technology development must be insulated from ongoing budget and political pressures. This is particularly true when considering the effect that the annual congressional budget process has on mission agency budgets. Financial support for pre-commercial R&D, channeled through mission agencies, has little chance of competing with long-standing basic research (and it should not) or with other technology objectives of mission agencies.

Moreover, even if resources were guaranteed a reasonable chance of successfully competing with existing programs in the budgeting process, it is unlikely that so decentralized an approach to support for industry in areas that require choices as to key technologies would result in identifiable, long-term benefits to U.S. industrial performance. We are even more convinced that this is the case in the absence of a stronger supervisory process than provided by present or likely White House mechanisms.

There are agency advisory groups, such as the President's Council on Science and Technology, the Federal Coordinating Council on Science and Technology administered by the White House Office of Science and Technology Policy, and the cabinet-level Domestic Policy Council that include technology policy in their mandates. These groups, however, lack administrative and budget authority to affect federal policy. Moreover, they are operated almost entirely by lower-level officials on a sporadic, part-time basis. The panel, therefore, has concluded that a new federal entity is needed to finance and organize substantial investments in pre-commercial R&D, including any selective expansion of mission agency programs.

A Civilian Technology Agency (CTA)

Another alternative for enhanced federal support for pre-commercial R&D is the establishment of a new federal agency within the current executive branch structure. In the past several years, Congress and congressional advisory groups have advanced proposals for a civilian counterpart to DARPA. For example, the proposed 1989 Trade and Technology Promotion Act would have established an Advanced Civilian Technology Agency to pro vide seed money to foster industry-led, public-private partnerships for the development and application of civilian technology.[10] Legislation with similar intent includes the Technology Corporation of America Act of 1990, to establish a nonprofit corporation for commercial R&D,[11] and the Economic Growth Act of 1990, to create an advanced technology fund administered by a national technology council.[12]

Organization and Structure

A civilian technology agency could be established within the current bureaucratic framework. The organization might be created as an administrative unit of an existing federal department, such as the Department of Commerce, whose current missions and mandate are tied to developing commercial technologies and to U.S. industry. There are other methods of establishing such an agency. For example, it might be created through reorganization of existing executive branch agencies into a Department of Industry and Trade, as provided by several recent legislative proposals in the 101st Congress.[13] Another option would be to establish the CTA as a separate agency, with the administrator reporting directly to the President. This approach would likely involve new or expanded staff functions in the White House, similar to the Space Council's link to the National Aeronautics and Space Administration. As is the case with other federal agencies, a Civilian Technology Agency would be funded on an annual basis by Congress. Moreover, the agency would have to conform to civil service personnel rules and federal government procurement guidelines.

As specified in the guidelines and operating principles outlined in the previous section, cost sharing of projects would be essential to ensure serious industry participation and guide projects into commercial market-oriented technology areas. For example, costs might be shared in consortia on a 50-50 basis, with industrial sponsors given an exclusive license to R&D results. As further evidence of serious intent, industry could also be required to make a multiyear commitment to projects. A small percentage of the agency's funds might be invested in R&D that is too high risk to attract private firms on a 50 percent contribution basis.

Most models for civilian technology agencies outlined in other reports view the structure of DARPA as a framework for such an organization.[14] The cost-sharing provisions endorsed in the panel's guidelines for an expanded government role in civilian technology, however, differentiate the CTA from a civilian counterpart to DARPA. The CTA would make grants available to companies and joint cooperative projects, as well as involve the private sector in project selection through advisory committee panels of experts in technology and business administration. Federal advisory regulations might present some problems in carrying out these provisions. Moreover, unlike

DARPA, the CTA's management might be set up under the general policy oversight, although not day-to-day direction, of a board of directors. The board would be comprised of representatives of government agencies, the private business sector, and other nongovernmental institutions.

The budget of the CTA would have to be large enough so that investments affect commercial market decisions. The CTA would be authorized to extend federal loan guarantees and to make investments in cooperative R&D projects. An important goal would be to keep administrative costs at a minimum. As is true at DARPA, a high percentage of agency funds, about 90 percent, should be devoted to technology development and R&D commercialization efforts.[15]

A CTA would require substantial funding over an extended number of years in order to support large-scale projects involving firms in a wide range of industry sectors. Projects that involve substantial start-up costs or that would benefit from a focus on vertical or horizontal integration in a sector might be among those emphasized by CTA management. Industries with the potential for long-term commercial benefit to the nation, such as advanced ceramics and high-and low-temperature superconductors, might merit special attention. CTA backing might help lengthen private sector time horizons in such cases. (Further discussion of technology areas for consideration are included below in the discussion of a Civilian Technology Corporation.)

Another focus of a CTA could be technologies with far-reaching importance to the nation's economic and technological base, such as new generations of semiconductors or advanced telecommunications networks that may not be receiving sufficient financial support from either the private sector or current mission agency programs. R&D projects on cross-cutting technologies that require research teams with multidisciplinary expertise, or work on technologies with potential for high add-on value, might also be considered.

Advantages of the CTA

The government currently has no formal system for evaluating and supporting important, nonmilitary technologies in a systematic fashion. There have been attempts at crafting "critical" technology lists in both military and civilian branches of government, as well as within private business groups. Not surprisingly, such lists closely resemble each other. These lists and accompanying suggestions have, however, no connection to the process through which government funding decisions are made. The CTA would place much of the authority and responsibility for long-term, strategic civilian technologies in a single agency.

A CTA would provide a mechanism for designing and implementing an organized approach to financing projects in sectors important to the nation's technological base and long-term competitiveness. The functional separation of the CTA from the activities of existing mission agencies would further facilitate its work by removing it from long-standing private and public sector constituencies that until now have served the purposes we contemplate.

Moreover, a new agency would give special status to technology commercialization, making it a legitimate purpose of the government. It would signal the importance of pre-commercial R&D to technology in strategic sectors, acting as a catalyst in promoting R&D even outside projects receiving CTA support. The success of DARPA in some projects to develop military and dual-use technologies under similar conditions suggests that a CTA has a reasonable likelihood of success, not only because of its role as a catalyst, but also because of its ability to manage a changing portfolio of investments.

Disadvantages of the CTA

A CTA would face several potentially serious obstacles. It would likely be dwarfed in size, budget, status, and influence (at least initially) by existing agencies. Its establishment would face opposition from agencies and congressional committees anxious to guard existing prerogatives over discrete technology areas. Unless its purpose were clearly defined and its authority affirmed, the CTA might simply add to the federal bureaucracy without achieving many concrete results.[16]

The most serious disadvantage of a CTA is its placement in the executive branch. This would increase the likelihood that support of projects would be influenced by the interests of Congress and executive branch officials. Congress might be expected to intervene in the planning and implementation of specific projects in order to satisfy regional special interests. An agency of the federal government, whether housed in an existing organization or independently controlled, is a central part of the political process. The closer to the political process, in most instances, the farther it is from the market process.

Placement of a CTA in an existing federal agency would likely distort its focus and intended mission. Forcing a new or reorganized agency to coexist with the sharply different missions of the Department of Energy, Department of Defense, Department of Commerce, or National Science Foundation could distort its original purpose. The potential for success of the CTA could also suffer as a function of its existence in agencies without specialized technical staff.

Furthermore, the operation of a CTA would rely heavily on recruitment of staff analysts skilled in evaluation of pre-commercial research proposals in civilian technology. None of the current mission agencies have staff competence or experience in this area. The creation of a CTA in one of the federal agencies would most likely do little to stimulate the establishment of such a group. Along with lack of experience, staff at a CTA would be subject to civil service rules that hinder recruitment of highly skilled, well-paid technical personnel from industry or universities.

A CTA would therefore have difficulty overcoming problems associated with post-employment restrictions for private sector scientists and engineers. Compensation rates that exceed government pay schedules would be impossible. Moreover, government procurement rules, which apply to most federal agencies, would limit the flexibility essential to establishing both internal and external R&D facilities and operations. A CTA created as a new agency outside existing departments would still be subject to these limitations. It is unlikely that a new and separate technology agency would be able to adopt the flexible personnel policies of agencies located in larger departments that have attracted motivated and highly qualified staff, such as the Office of the U.S. Trade Representative or DARPA, at least initially.[17] In sum, the disadvantages of a Civilian Technology Agency outweigh its potential advantages. There is a more efficient way to structure an extension of the federal role in civilian technology.

The Civilian Technology Corporation

The second option considered is fundamentally different from the one envisioned above. The Civilian Technology Corporation would be a new, private, quasi-governmental institution intended to guide financial support for middle-ground, pre-commercial R&D in key technology areas of significance to the U.S. technology base. Financing for the CTC would be made available through a one-time appropriation by Congress of $5 billion. This funding might be expended over a five-year period, although the CTC board could take longer to fully invest these funds in R&D projects. The $5 billion, if invested at a relatively rapid rate, would provide the capital necessary for up to approximately $1 billion in program expenditures per year. Funds might be allocated to firms by direct investment, for example. They might also be distributed on a contract basis or, in the case of loans and loan guarantees, administered by the CTC through financial institutions selected by the board.

As noted, to invest this capital fully, the CTC board of directors might require more than five years. Decisions about the duration and rate of CTC investment would best be made by the individuals in charge of such a program, in consultation with industry, government, and academic advisory groups. The panel believes it is preferable to move with some dispatch in order to have the best possible chance of affecting long-term commercialization rates in the United States. Program expenditures at the level of $1 billion per year would be sufficient to significantly affect commercialization efforts in a broad range of high-risk technologies through pre-commercial R&D funding. As noted in Chapter 2, current programs in the mission agencies that focus on pre-commercial R&D are not funded at a level that impacts private sector markets in a significant, measurable way. Funding of $5 billion would enable the CTC to make the necessary investments to affect technology commercialization rates in the United States in a wide range of sectors.

The CTC would be required to submit to Congress and the President a report on its activities after four years and again when the review begins—no later than the tenth year of operation. Depending on the results of the review, funding for the CTC might be augmented. Because it would be an experiment, if an independent review panel found that the corporation failed in its objectives, the corporation would be dissolved. This feature provides another important advantage over housing such an organization within the executive branch structure. Once agencies are created they are rarely dismantled, even when their mission or utility in meeting program objectives has diminished significantly.

Organization and Structure

The CTC would operate outside the existing government agency structure. The corporation, aimed at providing financial support to industry under the guidelines for all three options listed above, would also be insulated (to the extent possible) from overt political direction by either Congress or the executive branch. It would be guided by a board of directors, comprised of private citizens nominated by the President, and subject to confirmation by the Senate. This organizational structure offers several benefits, specifically when measured against the operation and real-time oversight of an executive branch agency. The CTC, by being separate from both the executive branch and Congress, would be closer to a "customer" in industry or to a potential adopter of the resulting R&D and technology results of projects conducted under its sponsorship.

The board would operate in the same manner as any private board of directors. It would choose a chief executive and would approve the selection of CTC projects. The CTC would be staffed by individuals with technical, business, and administrative expertise in civil research and technology development. It would also include a strong economics staff. The board would be called to consult frequently with officials of executive branch agencies, including the director of the Office of Management and Budget, the secretaries of energy and defense, the director of the National Science Foundation, and the director of the Office of Science and Technology Policy. Close consultation with these officials would help a CTC avoid dupli cation of ongoing agency research efforts. An advisory panel, similar to that established for the U.S. Trade Representative to conduct trade and policy negotiations, would be put in place. Advisory committees, focused on both technology and industry issues, would have monitors from industry, labor, and federal agencies.

Operation, Instructions, and Performance

As previously noted, distance from the political process is important to successful execution of R&D programs. We recognize that it is impossible and inappropriate to remove politics completely from the nation's R&D and technology investment programs. In the panel's judgment, however, it is possible and appropriate to limit these influences in R&D programs. A primary advantage of the CTC is its distance from the constituent-oriented political process. It would clearly be more distant from the political process than either a new agency of the federal government or a new department in an existing agency. An independent, quasi-governmental entity would increase the chance that decisions to invest in commercially relevant technologies are based on technical and economic grounds. Notably, in contrast to either an expanded program for mission agency funding of R&D or the creation of a new Civilian Technology Agency, a CTC would avoid the political pressures and discontinuity inherent in the annual appropriation process.

Placed outside government, the CTC would also have the advantage of flexibility in choice of investment. The corporation would have the latitude to choose which investment vehicles to use to support industry efforts in pre-commercial technology development. The CTC modes of support might include financing university R&D consortia (not subject to cost-sharing provisions), industry, and national laboratories or other projects related to technology and R&D. If the cost-sharing provisions outlined above cannot be satisfied by small companies, equity positions or venture arrangements could be established by the CTC board to facilitate their participation. On a case-by-case basis, CTC also would be able to recover cost-plus profit earned by technologies developed with CTC financing. Finally, companies that do not participate in CTC-supported projects would be able to license any CTC-financed technologies for a fee, after project participants have had a chance to exercise a right to an exclusive license.

The CTC's business objective would be to encourage cooperative R&D ventures in pre-commercial areas. These projects should have high expected social rates of return in areas in which individual firms (or groups of firms) are unlikely to invest because of the low probability of economic returns. A primary goal of the CTC would be to improve selectivity in the choice of R&D projects with high social returns on investment and signifi cant externalities for the economy. This would likely provide a greater channeling of federal funds to potentially useful projects than the types of tax policy incentives discussed above, for example. If successful, the CTC would provide for higher levels of R&D investment in pre-commercial areas in the United States and, over time, for a larger number of successful technology commercialization projects in the private sector. The government can affect technology commercialization rates to the benefit not only of a single firm or industry but also of the economy and welfare of the nation.

What types of investment might comprise the initial portfolio for the CTC? We believe that details on specific investment examples for the CTC should be determined by those directly responsible for the organization in consultation with specialists in science, technology, and economics. Investments made by the CTC would be in pre-commercial areas where the social rate of return on investments would be significantly higher than the initial, expected rate of return in the private sector. As noted in previous chapters, these areas would be identified by the existence of great initial externalities in projected benefits of successful R&D efforts to other sectors of the economy and might include, for example, energy R&D projects with the potential for enhancing productivity and long-term economic growth. In addition, CTC investments should be in projects initiated by industry. The frequent failure of previous government technology efforts suggests that industry commitment in the initial stages of project design and through all subsequent phases is a critical factor in promoting success.

The panel has considered several possible areas for initial investment by the CTC. These include advanced materials such as ceramics; environmental and energy-related technologies outside DOE's investments; microelectronics (to the extent that DARPA does not assume the leading role in this area); applied biotechnology such as protein separation and fermentation; information-processing technologies such as massive parallel processing, flat panel displays, and artificial intelligence (to the extent that DARPA does not assume this role); machine tools, such as computer-numerically controlled machine tools; nanostructures and nanomachines; technologies related to the construction of an Intelligent Vehicle Highway System; and technologies associated with the establishment of the National Research and Education Network (NREN) and High Performance Computer network, of which NREN is a part (to the extent they are not already being pursued by mission agencies of the federal government). Evaluation of CTC's success in promoting pre-commercial R&D in U.S. firms, in areas such as those outlined above, is an important element of this type of experiment. The CTC would have the flexibility to invest in either consortia, private firms with promising research agendas, or university-based R&D projects. As such, there should be no expectation that a diverse project portfolio, spread across different investment vehicles and technology areas, would produce a set rate of return. In any case, returns should not be expected to exceed those in private venture capital markets or even in corporate investment portfolios.

Evaluating the success of the CTC should not, therefore, be based primarily on the corporation's overall rate of financial return on investments. The most important criterion—long-term social (including overall economic) return—will be much harder to judge. After no more than 10 years, an evaluation of the CTC, conducted by an independent review panel of experts, might take into consideration the following: whether the CTC has had an overall positive impact on the ability of U.S. industry to commercialize and adopt new technologies; whether it has invested in projects that exhibited a high potential social rate of return if successful; and whether the CTC has elicited strong, continuing support in the private sector, particularly as reflected in the willingness of firms to fund cooperative R&D projects under its sponsorship.

Among the important advantages of the CTC are its freedom from operating under civil service guidelines. A highly skilled, motivated, and flexible staff is essential to any organization. The CTC, as an independent corporation, would be able to hire qualified scientists, engineers, business managers, academics, and administrative personnel by using competitive compensation packages. Clearly, a federal agency devoted to civilian technology would not be able to operate in this manner, pay nonfederal wages, and offer flexible, competitive benefit packages to attract the most highly qualified staff from the broadest possible labor pool. The CTC would be free of complex, slow, litigation-prone government procurement regulations. The CTC, unlike a new federal agency, would also be able to make direct loans and grants to ventures under terms acceptable to the board of directors. The CTC would have the flexibility to take direct equity ownership in R&D cooperative ventures, something not possible under current federal guidelines.

Finally, a CTC would be an efficient method of facilitating R&D investments by the federal government, over and above an across-the-board R&D tax credit. There are benefits associated with this tax credit, as noted above. Lowering the effective tax burden for corporations engaged in research and development is, however, insufficient to meet the objective of facilitating pre-commercial R&D in a wide range of technology areas and of increasing the rate of technology adoption by U.S. industry.

An organization to stimulate pre-commercial R&D investments would impact technology commercialization rates in a more systematic manner than current tax incentives for R&D. The board of the CTC would be charged with making investment decisions that narrow the possible portfolio of R&D projects in a manner that changes in the tax code cannot. In effect, corporations would have to meet a higher threshold or standard than simply investment in research and development. Moreover, the objectives of the CTC would be to stimulate investments in pre-commercial R&D to bolster the capacity of U.S. industry to commercialize technology. The R&D tax credit, in contrast, does not offer the flexibility of aiding firms that do not engage in R&D: incentives in the tax code are available only to firms that currently perform R&D. In theory, the CTC would operate to encourage at least some firms with limited financial resources that are just beginning R&D work. If increased R&D activity in pre-commercial areas is to be part of a changed U.S. technology strategy, it most likely will be more efficient to allocate funds directly for this purpose, through a mechanism like the CTC. Finally, tax credits have limited potential to affect rates of technology adoption or the diffusion of innovative technologies through specific programs tailored to meet this objective.

Disadvantages of the CTC

One disadvantage of the CTC (and of any similar, new organization) is that it cannot possibly be free of political influences. There would, very likely, be congressional and executive branch pressures on the CTC board and staff to fund projects with significance to political objectives and special interest lobbying. This important potential problem would be eased, however, by the involvement of both Congress and the executive branch in selecting the CTC board, by the lack of annual congressional appropriations, and by independent evaluation of the program content on a schedule such as the one outlined above.

Another potential disadvantage of the CTC (or any other federal program in pre-commercial R&D) involves the uncertainty and risk associated with investment in areas where there are no clear market signals. The type of investments the CTC would make are, by definition, high-risk ventures, and the success or failure of its portfolio would depend, to a great extent, on the wisdom and judgment of the CTC board of directors and staff. A key issue here is how to evaluate the success or failure of projects in which a CTC might invest.

The lack of a large number of commercial products resulting from CTC-funded ventures, even up to the 10-year review deadline, would not necessarily signify failure. In fact, projects funded by the CTC might meet the broad objectives of enhanced flow of information on technologies, speeding the rate of adoption of new technologies, and other benefits of R&D not captured in measurements that account only for commercial payback. The CTC should not be required to show a positive real rate of return on its investments. Zero or slightly positive real rate of return could, however, reduce the need for additional CTC appropriations, which would be a sig nificant advantage. Finally, a high rate of commercial success for CTC-funded ventures might signal that the projects were too close to commercialization at their outset. Some failures are to be expected in these types of investments; if there are none, it signifies that the choices could have been funded commercially.

Risk borne completely by the private sector, in investments made by venture capital firms, is arguably different from that shared by the public. This would be the case with a CTC funded through congressional appropriations. Even in a CTC, there will be criticism of any failure. For example, Congress often expects that R&D funds will be allocated only to successful scientific experiments, which is clearly neither possible nor desirable, and should not be expected. We believe that the safeguards and guidelines outlined above would ensure that the CTC's projects include those that promise high social rates of return and merit the risk of investing public funds.

The CTC would clearly be one step removed from potential customers in the private sector. Its risk of project failure, therefore, would be higher than that of a venture capital firm. As noted in Chapter 2, tight links between the performer of R&D and potential customers increase the chances for success of any technology program. The CTC, unless endowed with a substantial first-time appropriation by Congress, might be subject to political pressure to alter its project portfolio in order to offset a potentially high failure rate. In sum, acceptance of failures is an important part of any high-risk investment venture, even as successes provide payback to the nation's technology base.

There are also problems (evident with the CTA as well) associated with providing an organization with a mandate to support pre-commercial technology, without also providing guidelines on what specific areas constitute pre-commercial R&D. In theory, the CTC board might be able to draw on the expertise of outside groups of experts in an advisory capacity. Without a broad, industry-wide list of pre-commercial R&D areas to draw on however, and without specific understanding of investments that by definition are somewhat removed from the product stage of commercial markets, there remains—at least in the short term—reasonable doubt about the CTC's ability to guide its portfolio. Although various "critical" technology lists exist, the panel believes that they are too broad (and comprehensive) and insufficiently prioritized to provide a solid basis for specific investment decisions. The technologies cited in the growing number of "critical" technology lists would have to be narrowed by the CTC board. The final selection of projects may or may not be based on these lists.

SUMMARY AND CONCLUSIONS

This report has examined government-industry cooperation in civilian technology, with particular emphasis on analyzing methods to improve the technological performance of the U.S. economy. We have set out a series of recommendations to strengthen technology transfer from the federal laboratories and to increase the rate of technology adoption in U.S. industry (see Chapter 2). In this chapter, we propose guidelines to frame future R&D cooperation between government and industry, as well as possible structures to shape a new federal role in pre-commercial R&D support. These recommendations should not be viewed as a comprehensive plan to address U.S. industrial competitiveness. This report has specifically focused on the issues included in the panel's charge from Congress: U.S. performance in civil technology and the appropriate government role in this process.

The panel has considered options for a mechanism through which the federal government might extend its role in civilian technology. We believe that a very few of the existing mission agency's R&D programs should be extended to include pre-commercial research and technology commercialization. We have also concluded that this alone is inadequate to meet the objective of supporting technology commercialization over the long term. Funding under a plan of this nature would, most likely, not reach the levels necessary to affect commercial markets on an economy-wide basis. Moreover, a government program to encourage pre-commercial R&D and technology development requires distance from existing agency agendas and from continuing budget and political pressures. Financial support for pre-commercial R&D, channeled through mission agencies, has little chance of competing with long-standing basic research or technology needs of the direct objectives of mission agencies.

Even if available resources were guaranteed a reasonable chance of successfully competing with existing programs in the budgeting process, it is unlikely that a decentralized approach to support for R&D on problems that require choices of important technologies would result in identifiable, long-term benefits to U.S. performance. Finally, support for pre-commercial R&D to reach commercial objectives would clearly suffer in a program under the direction of agencies buffeted by political concern.

The panel has concluded that there is a legitimate role for the federal government in financing and organizing investments in pre-commercial R&D. We recommend creation of a Civilian Technology Corporation (CTC) as the most appropriate new mechanism for any further substantial federal investment in pre-commercial technology.

The details of how CTC would operate are best left to those individuals with responsibility for science, technology, and economic policy in government and industry. We do believe, however, that the CTC would offer a means to rationalize federal investments in nonmilitary technologies in a systematic fashion. The CTC would provide a mechanism for designing and implementing an organized approach to financing projects in sectors essential to the nation's technological base and its long-term economic advance.

Separation of the CTC from mission agencies would further facilitate its work and distance it from political considerations and control. The partial success of DARPA, under somewhat similar conditions, suggests that a CTC has some likelihood of success, providing industry helps to formulate R&D projects and participates in cost sharing. Specific advantages of the CTC include its freedom from civil service guidelines. The CTC, as an independent corporation, would be able to hire qualified personnel by using competitive compensation packages to compete in private labor markets. The CTC, unlike a new federal agency, would also have the flexibility to make direct loans and grants for pre-commercial R&D under terms acceptable to its board of directors. This includes the ability to take equity position in R&D cooperative ventures, something not possible under current federal guidelines.

NOTES

1. Kenneth Flamm and Thomas McNaugher, "Rationalizing Technology Investments," in *Restructuring American Foreign Policy*, ed. John D. Steinbruner (Washington, D.C.: Brookings Institution, 1989), 135-136.

2. William A. Cox, *Productivity, Competitiveness, and U.S. Living Standards* (Paper prepared for the Congressional Research Service, Library of Congress, Washington, D.C., 1991), 9.

3. The results of research and analysis on the effect of the R&D tax credit on industry's response to incentives are mixed. For example see Edwin Mansfield, "Studies of Tax Policy, Innovation, and Patents: A Final Report" (Paper prepared for National Science Foundation, Division of Policy Analysis and Research, October 1985) and Robert Eisner, Steven Albert, and Martin Sullivan, "The New Incremental Tax Credit for R&D: Incentive or Disincentive?" *National Tax Journal* (June 1984):171-183. The study by Mansfield found that firms would have reduced spending in the absence of a credit in the years 1981-1983, on average 1.2 percent lower in 1983, for example. The study also found that some firms might have reclassified activities that were categorized as R&D related (in the absence of a credit) or, in order to qualify for the credit, changed the composition of activities reported. Another study reported in Eisner et al. (1984) indicated that some of the positive response to the credit among firms may be associated with the substitution of one type of R&D for another. See Joseph Cordes, "A Survey of Research Findings on the R&D Tax Credit," in *The R&D Tax Credit: Issues in Tax Policy and Industrial Innovation*, ed. Kenneth M. Brown (Washington, D.C.: American Enterprise Institute for Public Policy Research, 1984). See also Joseph J. Cordes, "The Effect of Tax Policy on the Creation of New Technical Knowledge: An Assessment of the Evidence," in *Impact of Technological Change on Employment and Economic Growth*, eds. Richard M. Cyert and David C. Mowery (New York: Harper Business, 1988).

4. One study estimated, for example, that for every 1 percent reduction in the cost of R&D to firms, there is a corresponding increase in R&D spending of between 0.2 and 1.0 percent. Charles River Associates, *An Assessment of Options for Restructuring the R&D Tax Credit to Reduce Dilution of its Marginal Incentive*, Report Number 820.05, as cited in Martin N. Baily and Robert Z. Lawrence, *The Incentive Effects of the New R&E Tax Credit* (Washington, D.C.: Brookings Institution, July 1990), 3.

5. Baily and Lawrence, *Incentive Effects*, 3-4.

6. John A. Alic and Dorothy Robyn, "Designing a Civilian DARPA," *Optics and Photonics News* 1 (May 1990): 19-20.

7. See Albert H. Teich, *Federal Support of Applied Research and Development: A Review of the United States Experience* (Paper commissioned for a Workshop on the Federal Role in Research and Development, Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and The Academy Industry Program, Washington, D.C., November 21-22, 1985).

8. Flamm and McNaugher, "Rationalizing Technology Investments," 154.

9. SEMATECH restricts participation in its R&D activities to companies incorporated in the United States. Companies applying for ATP grants must have research and manufacturing operations in the United States or must have stockholding arrangements in which a majority of stocks are U.S. owned. NCMS requires permission to transfer technology developed under its sponsorship to foreign companies and to foreign subsidiaries of participating firms. (Canadian firms are excepted.)

10. S. 1978, 101st Cong., 2nd sess., 1990; H.R. 3833, 101st Cong., 2nd sess., 1990.

11. H.R. 4715, 101st Cong., 2nd sess., 1990.

12. S. 2765, 101st Cong., 2nd sess., 1990.

13. See, for example, *The Trade and Technology Promotion Act*, S. 1978, 101st Cong., 2nd sess., 1990; and *The Technology Corporation of America Act*, H.R. 4715, 101st Cong., 2nd sess., 1990.

14. See Burton I. Edelson and Robert L. Stern, *The Operations of DARPA and Its Utility as A Model for a Civilian ARPA* (The Paul H. Nitze School for Advanced International Studies, The Johns Hopkins Foreign Policy Institute, Washington, D.C., 1989).

15. Alic and Robyn, "Designing a Civilian DARPA," 20.

16. Some of the problems involved in creating a new federal agency are discussed in National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *Finding Common Ground* (Washington, D.C.: National Academy Press, 1991), 144-145.

17. Alic and Robyn, "Designing a Civilian DARPA," 21.

Appendixes

APPENDIX A

Background Papers

TECHNOLOGY TRANSFER: SELECTED CASE STUDIES*

John S. Wilson and Brent M. Haddad

INTRODUCTION: THE TECHNOLOGY TRANSFER CHALLENGE

In April 1990, the National Academy of Sciences and National Academy of Engineering sponsored a workshop on the diffusion and transfer of innovative technologies. The workshop was part of the Committee on Science, Engineering, and Public Policy's study of the government's role in civilian technology.

The primary objectives of the workshop were the identification of factors that contribute to successful technology transfer and of the impact collaborative technology transfer ventures have on the pace of technological change and technology commercialization. The discussions focused on technology transfer in three settings: within a single company; from one company to another; and from federal laboratories and universities to industry. The role

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* Vincent J. Ruddy contributed to the preparation of this summary.

of state, regional, and federal efforts to facilitate technology transfer was also discussed. Workshop discussions centered specifically on technology transfer within the biotechnology and automotive electronics industries. Participants also examined the federal government's role in facilitating technology transfer.

Four factors emerged as central to the discussions: the pace of technological change in each sector; the structure of the industry in question; private sector needs in spurring the commercialization of new technologies; and the relative competitive position of U.S. industry in international markets.

This summary synthesizes ideas expressed at the workshop. It does not represent a consensus opinion of participants in the discussions, members of the Panel on the Government Role in Civilian Technology, the National Academy of Sciences, National Academy of Engineering, Institute of Medicine, or National Research Council. This summary does not contain conclusions or recommendations.

INTRAFIRM TECHNOLOGY TRANSFER

Technology transfer that occurs within a single company is most commonly associated with large corporations, which often have organizationally and geographically separate research and development groups. Discussions during the workshop made it clear, however, that lessons from intrafirm technology transfer in large organizations may also be relevant to small firms.[1] In addition, the methods firms use to transfer ideas and information internally may prove effective for technology transfer between firms and among industry, academia, and government. Whether technology transfer takes place within a single firm or between two companies, the conditions for success often remain the same. Customer-supplier links are key to the process. They are needed both to facilitate technology transfer and to maintain competitive leadership, quality, and financial stability.

Mechanisms for In-House Technology Transfer

Corporations with in-house laboratory facilities face the challenge of moving technology between different operating divisions, as well as adopting technologies developed outside the company. This process, as it occurs at several large electronic firms, was outlined at the workshop. Technology transfer at one firm is aided by a "product and process development team" to a group of staff engineers, and other scientific and technical personnel. These individuals are the channels through which customers provide information on improvements in the firm's products and manufacturing processes.

Even when research laboratories and product or process development groups are in close proximity within a company, transferring technology between these two groups involves significant effort. A number of formal mechanisms to facilitate technology transfer and diffusion were mentioned at the workshop. Among the most important were:

- *Consultation*: Scientists often spend a considerable amount of time with product development personnel to help solve product-specific problems. This joint activity provides researchers with a view of product and process engineering that can improve their work once they return to their laboratories.
- *Transferring expertise*: One of the most effective ways to transfer technology is to move the individuals who have specialized knowledge to divisions within a firm. Many corporations use short-and long-term "internships" to transfer research personnel to areas of the company involved in product development, and vice versa.
- *Joint assignments and projects*: Removing the formal barriers between research and development can enhance technology transfer. Toward this end, some companies assign staff to both product development and research activities. Others bring full-time researchers and development engineers together on the same project.
- Other important, but less effective, ways of fostering technology transfer include distributing research reports and technical memos to development staff and conducting research seminars and product strategy reviews.

Workshop participants stressed that no single mechanism or approach to technology transfer is adequate alone to meet corporate technology development needs. Technology transfer is a complex, chaotic, and dynamic process that requires constant revision and change as the realities of the marketplace change.[2] Following the one-dimensional, "pipeline" view of technology transfer is no longer a viable strategy.[3] Several participants stressed that it was management's responsibility to encourage communication between groups within a firm. Management should also attempt to foster an atmosphere in which high-risk, innovative work is encouraged. Similarly, researchers should be shielded, to the extent practical, from short-term demands of the market. Employees who fear failure or delay will not take risks that may be critical to successful R&D projects.

An official at one company noted, however, that technology transfer does not happen just because management demands it or company policy calls for it. Individuals involved in research and product development must be motivated to undertake the steps necessary for successful technology transfer. This official also noted that simply because technology transfer is often a chaotic process, firms should not be discouraged from constructing a plan for achieving it. There must be clear objectives in any transfer strategy, with timetables and frequent revisions of original plans.

One method of stimulating technology transfer discussed at the work shop involves moving development engineers to research units prior to the period in which technology transfer is expected to occur. Over time, the number of manufacturing engineers assigned to projects increases, whereas the number of development engineers decreases. One large U.S.-based chemical company uses "business teams," comprised of individuals from marketing, manufacturing, research, accounting, and personnel planning, to increase information and technology flow within the company. It also has a central research department that, in addition to supporting applied R&D, enhances the company's innovative capacity while at the same time strengthening its ability to negotiate with other firms for important research-related information.

The firm's operating departments each have their own research divisions, but the central facility maintains a long-term perspective on R&D challenges facing the company. The system is referred to as "managed collaboration," in which technical staff and management officers with operating experience are integrated into a single corporate research division. Operating department R&D directors are rotated through the organization as directors of corporate research. This process brings business and management experience to the leadership of the corporate laboratory and increases understanding of corporate research goals in the departmental laboratories. Another company integrates its corporate and operating department research personnel and management in project-focused centers. Technology committees, staffed by R&D directors, ensure that institutional knowledge about specific business areas, such as polymers, energy, and health sciences, is shared by all operating departments.

In all in-house mechanisms to enhance technology transfer, company relationships with customers, vendors, and suppliers remain the key link to successful technology development. It was noted that many firms view these relationships as business partnerships and that companies must often work closely with suppliers, sharing data and personnel, to maximize chances for successful product and process technology development.

TECHNOLOGY TRANSFER BEYOND INDUSTRIAL LABORATORIES

In-house efforts to transfer technology from the laboratory bench into marketable products are vital to most firms that conduct research and development, and are part of a larger process that involves many individuals and organizations outside the company as well. From a corporate perspective, to varying degrees, technology transfer relationships with other firms, universities, and federal laboratories are also desirable. Although this interaction has usually been one-way—into the corporation, not out—many firms are discovering that sharing technologies with other organizations can con tribute to technology development goals. New relationships are being formed between and among corporations and their suppliers, through joint R&D ventures, cooperative agreements with federal laboratories, and university-industry partnerships. These new relationships reflect the importance of balancing cooperative and competitive interests in today's global economy.

From the university's perspective, technology transfer—both into and out of the university—can be productive, reflecting, in part, the academic tradition of free flow of information and expertise. Even in universities, however, the desire for professional prestige, the competition for scarce research funds, and the trend toward more extensive relationships with the private sector can reduce the flow of new ideas and technologies. As academic institutions seek to capitalize on the economic benefits from their research activities, these impediments to successful technology transfer may continue to increase in number and complexity. To state and federal governments, technology is viewed as a valuable resource that contributes to economic vitality and public welfare. Enhancing the diffusion and use of new technologies—especially those developed with the assistance of public funds—is a primary goal. Government agencies such as the National Institutes of Health (NIH), the National Science Foundation (NSF), and the Departments of Commerce, Defense, and Energy (DOC, DOD, and DOE, respectively) have also moved to stimulate technology transfer from federal facilities.

Mechanisms for "Cross-Boundary" Technology Transfer

Workshop participants spent a considerable amount of time discussing technology transfer involving "cross-boundaries." A number of the specific mechanisms used to encourage this activity are outlined below.

- *Industry-university cooperative arrangements*; Using this approach, corporations can gain valuable access to the university research community, and students and researchers can gain insight into commercial technology development. Several different types of programs exist, including joint research-industrial parks and the NSF's Engineering Research Centers. These relationships often involve funds from state, federal, and private sources.
- *Company-supplier relationships*: A number of steps can be taken to increase the likelihood of technology transfer between firms and their suppliers. Corporate engineers and engineers working for suppliers can spend time in each other's laboratories, for example. Joint R&D projects, between a firm and its supplier, have the potential for enhancing the success of product and process technology development. Finally, quality improvement programs, undertaken jointly by corporations and suppliers, can lead to more effective technology transfer.

- *Cooperative R&D ventures between competitors*: The benefits of cooperative arrangements include shared capital costs, economies of scale, and reduced risk, and can involve a considerable amount of technology transfer. U.S. corporations are increasingly working within such relationships. Whether they involve private firms only or combine the efforts of public and private entities, cooperative ventures can facilitate technology transfer and can result in technological breakthroughs. Moreover, federal and state governments can leverage investment in research and allow market forces to direct research agendas by requiring matching funds from private participants.
- *Cooperative Research and Development Agreements (CRADAs)*: Cooperative Research and Development Agreements were authorized by the Technology Transfer Act of 1986. Under a CRADA, a federal laboratory provides scientists and equipment for a particular industry-based research project; the company provides funding and its own scientists and equipment. CRADAs mentioned at the workshop that appear promising include those between NIH and small biotechnology firms. Many observers believe, however, that these agreements have yet to achieve their full potential to stimulate technology transfer and development. Participants identified a number of problems with CRADAs: they require a high level of technical sophistication on the part of industrial partners, which narrows the field of potential participants; "cultural" differences (with regard to incentives, recognition, and rewards) between private industry and federal laboratories can reduce the potential effectiveness of CRADAs; and a considerable amount of administrative oversight is associated with their operation. These difficulties contribute to an environment that inhibits technology transfer.

TECHNOLOGY TRANSFER IN AN EMERGING INDUSTRY: BIOTECHNOLOGY

The biotechnology industry is relatively young, having experienced rapid growth in the late 1970s and early 1980s. The founders of this industry, most of whom began their careers in university research laboratories, have been essential to technology transfer. The industry's rapid commercialization of discoveries is due in large measure to its continuing ties to academic research institutions and its openness in sharing the results of basic research. Another factor contributing to the development of the biotechnology industry centers on the availability of venture capital.[4]

As the industry matures, however, some of these advantages may no longer apply.[5] Workshop participants noted, for example, that as the founders of biotechnology companies retire, the industry's openness to academic laboratories is likely to diminish. In addition, some scientists who, in the past, had affiliations with both academia and industry are now less mobile be tween these sectors. Another potential problem, according to workshop participants, is conflict of interest. Policies intended to address real or perceived conflicts of interest, whether at the federal or the university level, may make it more difficult for industry and academia to maintain close ties in the future.

Participants pointed out that as investors increasingly focus on anticipated returns to investment in biotechnology, the flow of venture capital to the industry is slowing. Although this may simply reflect the maturity of the biotechnology industry, it may force some firms to reduce their levels of basic research funding and, as a result impair long-term competitive advantages. Participants noted that firms with access to capital markets and government research support, or those that operate under reduced regulatory scrutiny and transparent conflict of interest guidelines, would benefit.

Industry Strategies for Biotechnology Transfer

Representatives from the biotechnology industry discussed a number of strategies to encourage technology transfer. For example, many firms have established scientific advisory boards, whose members are drawn at least in part from academia. Not only do these advisors provide scientific expertise, they also are a link between the firms and university research laboratories. Other steps taken by the biotechnology industry that directly or indirectly result in technology transfer include the following:

- *Using CRADAs*: Involvement with federal laboratories is one method of leveraging R&D funds. In some instances, firms have calculated that problems associated with CRADA are less important than access to research conducted in federal laboratories, one participant at the workshop explained. Several commercially successful products are the result of CRADAs, including the AIDS drugs AZT (azidothymidine) and DDI, and the human immunodeficiency virus (HIV)-antibody tests. Other benefits of collaborating with federal laboratories include access to expensive state-of-the-art equipment and machinery, as well as technical assistance from federal researchers.
- *Licensing*: Several participants at the workshop expressed the view that product licensing should occur at or as close as possible to the time of a breakthrough. Waiting for patents, for the determination of all possible uses or even for the complete understanding of a new technology, can result in loss of potential returns. Biotechnology firms must be conscious of the needs and interests of academic collaborators when developing licensing strategies. Royalty reimbursement and technology-sharing arrangements can speed up the process of bringing an advanced technology to market by as much as five years, according to one participant.

- *Foreign patents*: Filing foreign patents, particularly for chemical reagents, is an important but often overlooked component of technology transfer. At least one company representative expressed the view that universities have not been sufficiently diligent in prompt filing of foreign patents.
- *Interaction with NIH and NIH-funded investigators*: NIH funds a significant amount of biomedical research, much of it on the cutting edge of science. Contact with investigators at NIH, and with researchers funded by the agency working in other organizations, has been an important factor in the success of the biotechnology industry.
- *In-house, state-of-the-art research capabilities*: One workshop participant noted that discoveries made by a firm's own researchers can complement advances made by scientists outside the company, and vice versa. It is not possible, the participant noted, to concentrate on external sources of technology and information and to neglect in-house R&D capabilities.

The University Perspective

Universities are facing many new opportunities as a function of increasing ties to industry. At the same time, these relationships challenge the historic mission of university education and research. University-based biotechnology research has been characterized by its close ties to industry and the potential for commercial market applications. New sources of funding, educational opportunities, enhanced possibilities for contributing to the public good, and profit are among the many benefits to universities from their industrial affiliations. There are potential problems, as well, such as conflicts of interest, the loss of top faculty to the private sector, maintaining a proper balance between research and teaching, and new sources of liability.

The passage of the Government Patent Policy Act of 1980 (Public Law 96-517) gave universities new patent rights for inventions developed with federal funds. Prior to this act, only about 4 percent of the more than 30,000 patents held by the federal government were ever licensed. According to one participant at the workshop, patents for inventions developed at universities with federal funding are now licensed approximately 50 percent of the time—an example of how market-based incentives can enhance technology transfer. Workshop participants discussed a number of other factors that can influence the success of university-industry partnerships in biotechnology, including the following:

- *Speed of licensing*: In biotechnology markets, licenses are often issued before a patent. The director of one university technology licensing office noted that, to issue licenses quickly, the institution involves lawyers only in the latter stages of the licensing process. In general, patents are not as important in biotechnology as in other sectors since products are often made by biological organisms, which are difficult to reproduce.

- *Role of university scientists in the licensing process*: University researchers who direct scientific projects often have insights about the selection of companies for licensing agreements. Participants noted that these researchers should be consulted early in the licensing process.
- *Product liability insurance*: The high cost of liability insurance makes it difficult for universities to license innovations to small companies, particularly in biotechnology. According to several participants at the workshop, some universities support remedial product liability legislation to reduce potential damages in these situations.
- *Biological materials*: Restricting the transfer of biological materials to other scientists was described as counterproductive to the goal of technology transfer.

The Role of NIH in the Transfer of Biotechnology

NIH has played an important role in the development and transfer of biotechnology products and manufacturing processes. The agency invests about $3.5 billion on biotechnology-related R&D, approximately 80 percent of the total spent by the federal government in this area. Approximately one-third of the $3.5 billion is spent on biotechnology-specific research; the remainder supports basic scientific research with wide biomedical applications.

NIH has several in-house units dedicated specifically to technology transfer. One is the Patent Policy Board, which has a number of working subcommittees, including one that reviews CRADA proposals and a second that focuses on royalty distribution. In addition, each of the agency's institutes has a technology development coordinator responsible for monitoring CRADA documentation and acting as a liaison with private firms on technology transfer activities.

NIH representatives at the workshop expressed the view that CRADAs are a productive method for small biotechnology firms to leverage internal R&D resources. The agency has approximately 130 CRADAs in place, of which approximately one-third are with small businesses. NIH also facilitates technology transfer by licensing patented materials and by training postdoctoral students and research fellows. NIH researchers are responsible for the publication of approximately 7,000 technical journal articles each year, as well as presentations at scientific workshops. Both of these activities involve technology transfer objectives.

It was reported that NIH also operates an electronic bulletin board containing lists of technologies available for licensing (identified and sorted by key words and names of researchers interested in collaborating) and that it will allow texts of patent applications, copies of policy guidelines, and model agreements for cooperative research to be down-loaded to personal computers.

TECHNOLOGY TRANSFER IN A "MATURE" INDUSTRY: AUTOMOTIVE ELECTRONICS

Universities have played a much smaller role in the technology transfer process in automobile electronics than in biotechnology, according to the director of an academic electronics laboratory. Instead, the automotive industry has relied on in-house R&D capacities and, more recently, worked with the aerospace, computer, semiconductor, and electronics industries.

The director of electrical engineering at one U.S. automobile manufacturer told the workshop that most development work in automotive electronics is performed either in-house or through private sector collaborative R&D projects. There is much less interaction with U.S. universities, he reported. With the exception of a project involving the Department of Energy to develop an electronic car, one participant noted that there has been limited interaction with federal facilities.

Participants also noted that in automotive electronics, the federal government has promoted technology transfer primarily through federal regulatory control. The Clean Air Act of 1970 and the establishment of the Environmental Protection Agency provided the incentives for the automotive industry to use electronics to control tailpipe emissions. Other incentives for developing new technology came with the establishment of corporate average-fuel-economy requirements. In the 1980s, market incentives led to electronic advances in antilock and antiskid braking, digital instrumentation, and intra-and extravehicular communications.

Although advances in aircraft design can in some cases be applied to automotive transportation, a number of barriers exist to this form of technology transfer. For example, under DOD sponsorship, aerospace electronics are developed and manufactured without cost considerations, a critical factor in private sector technology strategies. Similarly, performance requirements for the technologies differ. Differences in design methodology and management style between the two industries have also served to hinder technology transfer. For instance, only recently did the automobile industry start using a true systems engineering approach (standard practice in the defense industry) to develop new vehicles. Rapid technology transfer is also inhibited due to the fact that upstream electronics developers, particularly those developing defense-related technologies, have different cost and performance requirements. Frequently, auto companies must redesign electronics to meet these requirements.

Technology transfer in this sector has also been characterized by in creased collaborative R&D partnerships with suppliers. In the future, some workshop participants predicted, there will be increased emphasis on joint ventures, especially with foreign partners. Collaborative agreements with specific, applied technology goals may become more common. In addition, suppliers will be increasingly responsible for the development of new technologies, and acquisitions as a form of technology transfer may increase in frequency, according to participants. One official of a U.S. electronics company indicated that a number of other factors have contributed to successful technology transfer in automotive electronics. Many of these center on market incentives. For instance, many electronics firms have been willing to transfer technology to the automotive industry to help create new markets for their products. Automobile manufacturers view these developments as opportunities to enhance the customer appeal of their products through increased use of electronic components in autos.

One example of government support for automotive-related technology transfer discussed at the workshop is the Combustion Research Facility funded by DOE. The facility has a staff of approximately 80 government scientists and engineers, and an equal number of visiting staff from academia, industry, and other laboratories. Each year the facility hosts approximately 800 visitors, which facilitates the diffusion of technology. Automotive industry representatives help set the facility's research agenda through involvement in project R&D working groups.

FEDERAL EFFORTS IN TECHNOLOGY TRANSFER

Federal efforts to enhance technology transfer have increased over the past decade.[6] Formal links between government facilities and the private sector remain limited, however, in contrast to intrafirm collaborative arrangements.[7] One federal initiative discussed at the workshop, the National Center for Manufacturing Sciences (NCMS), involves R&D in support of the machine tool industry. NCMS, a consortium of 120 member companies established under the National Cooperative Research Act of 1984, provides technology outreach to small firms that make up the industry.

Technology transfer can also occur when an organization has specific product development requirements. In cases such as this, it may contract with a federal laboratory to carry out the necessary research. The Department of Energy is also moving to enhance its technology transfer activities, an agency official told the workshop.[8] Among the mechanisms DOE is using to transfer technology to the private sector are Superconductivity Pilot Centers that have industry-driven research agendas and require cost sharing. Similar efforts are the Clean Coals Technologies Program, DOE involvement in the Small Business Innovation Research Program, the Energy Conservation Utilization Technology Program, the Advanced Manufac turing Initiative, and the Specialty Metals Processing Consortia. In the future, one official reported, DOE will increasingly interact with R&D consortia, state organizations, and other federal agencies in technology transfer activities.

DOE is also developing model agreements for technology transfer, as well as systems for conflict management, so that technical problems do not inhibit technology flow. A DOE official noted that much of the agency's future efforts in technology transfer will be framed by the National Energy Strategy, which among other objectives is targeted at expanding investment in basic research and increasing the number of scientists and engineers engaged in energy research.

The 1988 Omnibus Trade and Competitiveness Act established programs targeted at technology transfer, including the Manufacturing Technology Centers (MTCs) managed under the sponsorship of the National Institute of Standards and Technology (NIST).[9] MTCs are designed to assist in modernization of the approximately 100,000 small (50 employees or less) parts manufacturers in the United States. MTCs are located in nonprofit and academic institutions to leverage existing state and local information networks. As of April 1990, three MTCs had been established.

Another NIST initiative is the Advanced Technology Program (ATP), which in 1989–1990 had funding of $10 million; this program of financial awards to industry and industrial consortia aims to speed the commercialization of emerging technologies.[10] Workshop participants noted that, although the federal government can play an important role in technology transfer through these and other programs, the government should not determine what specific technologies industry should develop. Similarly, government should not have final authority over how industry and government collaborative ventures operate. These choices need to be made in partnership.

REGIONAL AND STATE TECHNOLOGY TRANSFER

There are important regional economic issues that affect the technology transfer process. One workshop participant argued that the U.S. economy should be viewed as a series of highly concentrated industrial regions. In certain areas of the United States, there is a critical mass of qualified personnel, public R&D support, investment capital, and a technology and manufacturing base to sustain competitive firms. These regions often include distinguished universities and a core of industrial firms that perform advanced R&D.[11] Highly skilled scientists and engineers, for example, are often concentrated in these areas. The challenge for these regions, one participant noted, is to maintain and improve the R&D infrastructure to stimulate industrial development. Some areas in the United States are succeeding at this; a strong measure of success is the level of private industrial

R&D funding expended within a region. Where industrial R&D funds are concentrated, one participant argued, there has been strong regional economic growth.

One state technology development official noted that state efforts in R&D and technology transfer often focus on economic development, job creation and training, and technology commercialization activities.[12] In contrast, federal efforts in this area have traditionally focused on basic research capabilities and R&D funding. At the state level, technology transfer management is often decentralized. Decisions on resource allocation are made by member firms, which are often required to invest corporate funds in technology projects that the state sponsors. States have adopted many approaches to stimulate technology transfer. Several have established research centers and distributed R&D grants to individuals and firms, similar to the individual investigator grants awarded by NIH and NSF. Others have invested pension funds in venture capital organizations that target technology commercialization.

Ohio's Edison Technology Centers and Pennsylvania's Ben Franklin Partnership Program are two examples of state technology transfer initiatives. Several of the nine Edison Technology Centers operate contract research facilities whereas others are housed at universities. All centers are operated as private, nonprofit organizations. Membership fees, charged on a sliding scale, can be as high as $60,000 per year. These funds are used both to upgrade the infrastructure of the centers and to fund member-directed research. By contrast, the Ben Franklin Partnership Program acts primarily as a technology extension agent, bringing firms together with specialists in corporate management, education, training, and R&D.[13] Technical extension services operated by the states, it was argued, can also improve access to new technological information. According to some participants at the workshop, both small and large firms should be targeted by state and local extension services. A state industrial extension service, organized in a fashion similar to the farm cooperative model, would not only help improve technology transfer but also stimulate technology adoption by small and medium-sized manufacturers, participants noted.

SELECTED FEDERAL LAWS AFFECTING TECHNOLOGY TRANSFER

Brief Description

- P.L. 94-282, *National Science and Technology Policy, Organization, and Priorities Act of 1976*: Outlines science and technology policy goals, establishes Office of Science and Technology Policy (OSTP), Federal Science and Technology Survey Committee.

- P.L. 96-480, *Stevenson-Wydler Technology Innovation Act of 1980*: Directs Secretary of Commerce to establish Office of Industrial Technology; establishes Centers of Industrial Technology, and allows each center to assign intellectual property rights, licensing ability; allows secretary to make grants and enter into cooperative agreements to accomplish the above; directs National Science Foundation to provide assistance for establishing centers; allows centers to seek money from other agencies; establishes National Industrial Technology Board; requires federal laboratories to establish an Office of Research and Technology Applications; establishes in the Department of Commerce a Center for the Utilization of Federal Technology; establishes National Technology Medal; requires establishment by secretary and NSF of science and technology personnel exchange program; authorizes funding through fiscal year 1985.
- P.L. 96-517, *Government Patent Policy Act of 1980*: Allows government-owned, government-operated laboratories to grant exclusive licenses to patents.
- P.L. 98-462, *National Cooperative Research Act of 1984*: Allows joint R&D programs; limits damages to single rather than treble in antitrust suits.
- P.L. 98-620, *Trademark Clarification Act of 1984*: Amends P.L. 96-517 to allow contractors to receive patent royalties for use in R&D, awards, or education; permits private companies, regardless of size, to obtain exclusive licenses.
- P.L. 99-159, *National Science Foundation Authorization Act for FY 1986*: Repeals provisions for financial and other conflict-of-interest statements by NSF officials and employees; repeals prohibitions against outside employment and activities; prohibits public disclosure by NSF of certain industrial and business sources of information.
- P.L. 99-382, *Japanese Technology Literature Act of 1986*: Amends Stevenson-Wydler Act to direct DOC to improve availability of Japanese technical literature to U.S. businesses, scientists, and engineers.
- P.L. 99-502, *Federal Technology Transfer Act of 1986*: Amends Stevenson-Wydler Act to authorize government-operated federal laboratories to enter into cooperative R&D agreements with other entities; establishes Federal Laboratory Consortium for Technology Transfer; directs that federal laboratory science and engineering professional duties include technology transfer; requires cash award programs to be established; includes formulas for distribution of royalties from licensing or assignment of inventions (defense program laboratories excluded).
- P.L. 100-107, *Malcolm Baldrige National Quality Improvement Act of 1987*: Amends Stevenson-Wydler Act to establish National Quality Award for U.S. companies.
- P.L. 100-418, *Omnibus Trade and Competitiveness Act of 1988*: Amends

U.S. trade law provisions with respect to (1) U.S. trade agreements; (2) enforcement of antidumping provisions; (3) protection of intellectual property rights (Section 5171); (4) trade adjustment assistance; (5) changes in tariff schedules; (6) export promotion; (7) international debt; and (8) education and training programs to increase U.S. industrial competitiveness. Creates state and local clearinghouse coordinating body at Department of Commerce; changes National Bureau of Standards to National Institute of Standards and Technology; expands mission to include technology transfer activities (Manufacturing Technology Centers, Advanced Technology Program, State Technology Extension Services, and others).

- P.L. 100-519, *National Institute of Standards and Technology Authorization Act for FY 1989*: Amends Stevenson-Wydler Act to establish Technology Administration in the Department of Commerce, headed by new Under Secretary for Technology; consolidated into Technology Administration are the Office of Technology Policy, Office of Commercial Affairs, NIST, National Telecommunications and Information Administration, and National Technical Information Service.
- P.L. 100-656, *Small Business Competitiveness Demonstration Program Act of 1988*: Amends Small Business Act to set forth specified small business eligibility requirements with respect to the Small Business Administration small business and capital ownership development program and the award of government procurement contracts under the small business set-aside program.
- P.L. 100-676, *Water Resources Development Act of 1988*: Authorizes U.S. Army Corps of Engineers laboratories and research centers to enter into CRADAs.
- P.L. 101-510, *Defense Authorization Act for FY 1991*: Begins development and implementation of a National Defense Manufacturing Technology Plan; allows federal laboratories to enter into memoranda of understanding (MOUs) with intermediaries to facilitate cooperative work with small businesses; establishes model programs for national defense laboratories to demonstrate successful relationships between federal, state, or local governments and small businesses.
- P.L. 101-189, *National Competitiveness Technology Transfer Act of 1989*: Extends technology transfer mission to DOE defense program laboratories; allows these facilities to enter into CRADAs.
- P.L. 102-245, *American Technology Preeminence Act of 1992*: Amends Stevenson-Wydler Act to extend the Federal Laboratory Consortium mandate through 1996; allows sharing of intellectual property as a contribution to a cooperative R&D agreement; request DOC judgment on whether to allow federal contribution of funds to a cooperative R&D agreement; allows laboratory directors to make gifts of excess laboratory equipment to schools and nonprofit organizations.

COLLABORATION IN RESEARCH AND DEVELOPMENT: SELECTED EXAMPLES*

John S. Wilson

INTRODUCTION

A research consortium is generally defined as an association of organizations involved in collaborative R&D projects. The goal of most collaborative research ventures is to leverage both scientific and engineering expertise, and financial resources. In practice, research consortia take many different forms, including interfirm collaborations, public-private ventures, and university-based projects.[14] The relationships among consortia members, and their financial and other responsibilities, vary. Consortia participants often use different measures to assess the value and effectiveness of their involvement in collaborative R&D.

In March 1991, the project on the Government Role in Civilian Technology and the Academy Industry Program convened a workshop to assess recent experiences with research consortia. Leaders from industry, government, and academia participated in the discussions. The objective of the session was to identify both the characteristics of successful collaborative R&D projects and the obstacles to such efforts.

This paper summarizes the workshop discussions, highlighting key points and issues raised by participants. It does not represent the views or conclusions of speakers or participants at the workshop. This summary does not contain conclusions or recommendations of the Panel on the Government Role in Civilian Technology, Academy Industry Program, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, or National Research Council.

OVERVIEW

Although the past decade has witnessed an increase in the number and diversity of collaborative R&D projects, such activities have been going on for many years in the United States.[15] Development of the computer and the integrated circuit, for example, can be traced to research sponsored and coordinated by the U.S. government during the 1950s and 1960s. The nation's space program was built on collaborative R&D ventures involving government, industry, and universities. The biotechnology industry is largely the product of federally funded research carried out at U.S. universities.

The relatively recent increase in the formation of R&D consortia re

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* Mark Bello contributed to the drafting of this summary.

flects new economic and technological conditions in the global economy.[16] Principal among these is the quickening pace at which discoveries and inventions are applied to new commercial products and processes. The global diffusion of new technology and the results of research, combined with the enhanced manufacturing competency of nations, have resulted in intense domestic and international competition in many products and processes. From the innovation phase of technology development to the final commercialization, manufacturing processes and R&D have undergone significant changes over the past several decades. The effectiveness of collaborative R&D ventures should be viewed in light of these changing conditions.

The interactive character of the technology commercialization process is illustrated by the metaphor of athletic competition, as one participant at the workshop noted. Traditionally, the stages leading from invention to marketable product or process improvement have been described as legs in a relay race—sequential and largely discrete stages. Each step in this process involves different personnel, scientific and engineering resources, and facilities. Increasingly common, however, are simultaneous interactions among basic research, applied R&D, and product design and development. In a game, the ball is passed back and forth between team members, just as innovation is advanced by groups working in concert, regularly exchanging designs, prototypes, and manufacturing and marketing plans. In industries with short product life cycles, all elements of product or process development require quick turnaround. Time to market is a critical determinant of success.

Congress and the executive branch have attempted to create an environment in the United States that will accommodate this new dynamic.[17] For example, in 1984, Congress passed the National Cooperative Research Act (NCRA), which relaxed antitrust regulations to permit firms in the same industry to collaborate on pre-commercial R&D. Since fiscal year 1985, more than 250 consortia, involving more than 1,000 U.S. businesses, have been formed. Although the number of ventures filing for exemption with the Department of Justice under NCRA has increased, the effect of the law on stimulating collaborative relationships among firms is less clear, some participants noted.

In several technology areas, the federal government has provided increased funding for public-private ventures. The most notable example is the Semiconductor Manufacturing Technology Research Corporation (SEMATECH), a consortium of 14 U.S. semiconductor manufacturers. SEMATECH, authorized for five years in 1987 with a $200 million annual budget, was charged with making the United States a world leader in semiconductor technology. SEMATECH's funding is provided by consortium members and the Department of Defense. Since SEMATECH, the federal government has launched several other joint industry-government R&D programs.

The Federal Coordinating Council for Science, Engineering, and Technology, in consultation with university and industry representatives, recently proposed a new government-industry collaborative venture: a High Performance Computing and Communications Program. The program would combine the efforts of federal agencies, universities, and U.S. businesses to extend the U.S. leadership in advanced computing and networking. It also would be targeted at accelerating the development and application of technologies for commercial, educational, and environmental uses.

Universities, which conduct about half of all basic research in the United States, have become increasingly involved in collaborative R&D activities. One-to-one relationships between faculty members and industry scientists are the most common form of these efforts. During the 1980s, there was also an increase in more complex, formal, university-based R&D partnerships with industry. The National Science Foundation has also sponsored university-based R&D centers (the Engineering Research Centers), which serve as focal points for collaborative projects between academia and industry.

Promise and Outlook for Consortia

In the changing environment for technological and economic competition, consortia may complement other methods of strengthening U.S.-industry research and development. For private firms, the advantages of collaboration include reducing the risk and costs of R&D work, eliminating duplication of effort, leveraging internal resources, and gaining access to technology and expertise not available in-house.[18] Collaborative R&D projects are often centered on long-term, applied research. Several workshop speakers suggested that collaborative projects should focus on research horizons of two to seven years, the shorter time frame for industrial R&D, and the longer for basic research.

Consortia have been proposed as a mechanism to link public and private sector activities for promoting national economic interests. To date, however, most R&D consortia should be viewed as experimental, participants noted. Their value as strategic tools for altering the dynamics of industrial development and technological advance is unclear. Proprietary research conducted in industrial laboratories remains the primary focus of industrial R&D activities in the United States and most other nations. In Japan, for example, most research is performed within individual firms, and of the one-third of projects classified as collaborative R&D, most involve firms that do not compete in the same product markets.[19]

Several workshop participants noted that consortia face many of the same pressures and obstacles that confront in-house research programs. They pointed out, for example, that collaborative ventures must produce quick results, even though one rationale for forming partnerships is to lengthen research horizons. Moreover, participants noted that the transfer of research results to member firms is more complicated than simply passing an innovation to an industrial sponsor. They also stressed the importance of sustained interactions between consortium researchers and those in industry who are involved in process and product development. One participant suggested that describing consortia as R&D centers is counterproductive because it implies a separate island of activity rather than a continuous innovation cycle.

PRIVATE SECTOR COLLABORATION

The United States' experience with collaborative R&D extends to the early post-World War II era, when U.S. industry first became involved in research—focused on supercomputers, aircraft, and semiconductors, for example—to develop technologies for use in military hardware. Collaboration between industries associated with aerospace efforts of the National Aeronautics and Space Administration in the 1950s spurred joint R&D efforts in the commercial aircraft industry. Prior to the 1970s, collaborative industrial R&D efforts that were not directly supported by the government occurred among companies in vertical sectors. Such was the case with automobile manufacturers and petrochemical firms collaborating to develop ceramics for use in auto bodies, for example.

Today, joint R&D consortia involving manufacturers in horizontal business sectors—such as semiconductors, chemicals, advanced materials, and telecommunications—are on the increase. The Semiconductor Research Corporation, Microelectronics and Computer Technology Corporation (MCC), and Software Productivity Consortium, are examples of collaborative efforts that bring together companies in similar product markets.

Prior to 1984, U.S. antitrust law limited horizontal R&D collaboration. Collaboration among firms in the same industry, therefore, was most often carried out under the sponsorship of trade associations. Trade association activities included work to establish industry-wide technical standards, for example. Regulated industries, such as the gas, electrical power, and telecommunications sectors, were permitted to engage in collaborative ventures because firms in these industries were not in direct competition.

Private Sector Perspectives

Representatives of several firms at the workshop described collaborative R&D ventures, relatively uncommon during the early 1980s, as an integral part of today's corporate research efforts. One research director reported that his company considers joint R&D projects so important that it has made collaboration a core competency objective of the firms' competitive strategy. To that end, the firm has developed a process model for planning, guiding, and evaluating collaborative projects. Under this framework, the firm cooperates with suppliers, participates in multicompany consortia, and is active in "centers of excellence" that it sponsors on university campuses. The method used by the firm to assess its success in R&D collaboration is patterned after the total quality control model employed in manufacturing processes. Among other features, it allows the company to measure how its performance compares with that of other firms involved in collaborative research. Workshop discussions revealed several common motivations for collaborative research. The importance attached to each anticipated benefit, outlined below, varied among firms.

1. *Acquiring needed expertise*: Firms with diverse product lines in rapidly evolving industries often require the R&D expertise of many scientific and engineering disciplines. Even companies with large R&D budgets, however, are not likely to have all the necessary personnel in-house. Collaborative ventures give firms access to outside sources of talent, which cost the company less in terms of both human and financial resources than R&D work performed in-house.
2. *Leveraging research investments and building "critical mass"*: Cost sharing enables firms to both intensify efforts in specific R&D areas and expand their research agendas. For large projects that are too expensive and too risky to undertake alone, consortia may be the only alternative to forgoing promising research inquiries.
3. *Building technical competence, monitoring technological progress* : R&D collaboration can help a company build research competency in areas of technology development where its competitors currently have the lead. Similarly, collaborative activities permit firms to monitor progress in fields important to their future technological advancement.
4. *Acquiring intellectual property*: Even in areas where a firm leads the competition, collaborative research may, through the generation of ideas for new products, strengthen the company's market position. By adding to its portfolio of patented intellectual property in a particular area, a firm can enhance its competitive advantage.
5. *Improving research efficiency*: Noting the problems associated with the "not-invented-here syndrome," several corporate research directors stated that research needs, in some instances, can be addressed more efficiently by working with outside organizations. If fundamental proprietary advantages are not sacrificed, collaboration may be the best or only way to accomplish specific research goals.
6. *Facilitating the development of standards*: In the computer and

> microelectronics industries, the need for interoperable hardware and software facilitates R&D collaboration. Hardware manufacturers and software publishers must work together to develop industry-accepted standards for their products.

Elements of Effective Collaboration

Before a company establishes collaborative R&D ventures, one research director at the workshop maintained, it must have a clear vision of where it wants to be two, five, and ten years in the future. It must have short-and long-term R&D strategies. Firms should also fully understand their relative strengths in areas viewed as critical to current and future success. On the basis of that understanding, a firm can determine how best to allocate its research funds and whether accomplishing specific objectives will require work with outside organizations.

Workshop participants suggested that the most successful collaborations are based on a close working relationship among researchers. They stressed, however, that collaborations must not be viewed strictly as activities involving research personnel. Collaborative projects should have "champions" at each level within a company or operating division. Close and continuing contact between scientists and the managers or technical personnel who will eventually apply research results to products or processes is essential to technology transfer.

One objective of collaborative research is to advance the state of the art in a particular area of science or engineering. To do this, several participants stressed, collaborative R&D ventures must have clearly defined goals. One company research director suggested identifying broad areas of interest and then selecting a few projects to focus on. If the focus of a collaborative project is wide, priorities may be obscured and the effectiveness of the effort may be diminished.

Returns to Cooperative Research

Collaborative projects are judged on the basis of their accomplishments. A new product or more advanced technical application for existing product lines, manufacturing process technology improvements, and enhanced scientific understanding of physical or chemical processes all reflect successful collaboration. Not every project will "succeed" according to these criteria, one computer R&D laboratory director noted. Other measures of progress, such as a better understanding of the topic being investigated, are also important. Periodic and end-of-the-project evaluations can yield insights into improving future collaborative endeavors, he noted.

Perspectives of Consortium Managers

R&D consortia offer a number of potential benefits to member firms, according to one consortium official involved in semiconductor, computer, and software systems R&D. Efficiencies result from sharing the costs and risks of research and from reducing R&D duplication. Consortia can also monitor and fund university research, as well as serve as vehicles for integrating and transferring the results of that research. Collaborative R&D arrangements may promote the development of standards for specific technologies. In the semiconductor and information technology industries, for example, collaboration can advance the development of standards and protocols for hardware, software, and communication networks. One such industry-wide activity, undertaken by SEMATECH, qualifies and certifies vendors that supply materials and equipment to member firms.[20]

Outside Pressures and Changing Circumstances

To be successful, collaborative research ventures must be structured and operated in ways that are consistent with the realities of corporate R&D, participants noted. For example, although consortia are often viewed as mechanisms to facilitate long-term research, most companies invest in short-term R&D, an emphasis that may influence how they judge the value of investments in collaborative R&D projects. Rather than focusing exclusively on long-term projects, it was suggested consortia should accommodate a mixture of projects with varying time horizons. Plans for R&D projects should be reviewed periodically and revised to reflect circumstances, such as changes in membership. Consortium managers and researchers should recognize that their organization represents only one of several options available to companies pursuing their corporate research goals. Finally, it was noted that consortia management needs to understand that breakthrough research advances may be less important than continuous, incremental improvements in processing, product quality, marketing, and customer service. Understanding these elements of success can lead to productive redirection of consortia activities.

Enhancing Technology Transfer

A plan for transferring the results of research conducted by consortia must be established, in as detailed a manner as practical, at the start of the collaborative venture, according to several workshop participants. Participants also suggested that R&D sponsors maintain regular contact with researchers to facilitate the exchange of ideas, prevent surprises, and foster company ownership of the research products. It was stressed that the results of collaborative research can rarely be used immediately by sponsors. Typically, additional investment and effort are required to commercialize a technology or to apply a new processing technique effectively. Firms not familiar with the way research results are transferred to marketable products are unlikely to make this important allocation of resources.

In one innovative approach to technology transfer, the Microelectronics and Computer Technology Corporation, in Austin, Texas, is creating start-up companies to commercialize the products of consortium research. MCC owns a small stake in the new firms, and consortium members that sponsor research leading to a new product are charged preferential rates if they license the technology. One workshop participant suggested that this approach may foster better vertical integration between suppliers and member companies.

Other Issues

Sharing Technology and Information

There have been problems associated with technology and information sharing in most collaborative ventures. For example, some members of R&D projects have been reluctant to delegate highly qualified staff to collaborative projects. Others noted that firms in collaborative R&D projects face difficulties in sharing technology and technical information with other members. Workshop participants observed that in most collaborative ventures, participating companies must share intellectual property with other firms. There is a clear risk of losing proprietary technologies to competitors; however, firms should agree to a set of rights and responsibilities at the outset of projects. Clear intellectual property rights guidelines cannot, however, eliminate all risks. In the case of a firm sharing technology with a key supplier, for example, there is the danger that the supplier will sell this newly gained knowledge to other customers, who in turn compete with the innovating firm.

Based on one research director's experience, however, there is little evidence that collaborative R&D projects lead to the loss of key technologies or proprietary information. In the computer and microelectronics industries, he reported, product life cycles are usually so short that, even if a new technology is revealed to other firms, the competitor is still not likely to be the first to market. When firms are successful in taking advantage of intellectual property developed by another company, any advantage is usually short-lived. The exception, he noted, is for breakthrough technologies that create entirely new business opportunities and markets.

Number of Participating Firms

An executive from one firm suggested that as the number of sponsoring firms grows, the value of the research diminishes for each sponsor. Conversely, he noted, if a particular area of R&D is deemed critical to a company's success, the firm will be more likely to perform the work in-house. Therefore a small number of participants in a venture might be more effective than large numbers of firms, it was suggested. Research activities conducted under this framework might be more closely aligned with the sponsors' interests, and therefore the motivation for close involvement would be stronger. Compared to small (two-to four-member) collaborative projects, partnerships with many sponsors have more difficulty defining common interests and goals. Industry representatives and consortium managers reported, however, that there are no specific rules for determining the optimal number of collaborators for specific projects. One participant noted that individual firms must determine whether a partnership is required to accomplish a specific R&D objective. If such an arrangement is necessary, companies should then determine the specific type of collaboration that will best serve the firm's long-term R&D needs.

Collaboration Beyond Research

Technological innovation is only one contributor to a firm's competitive performance. Several workshop participants maintained that consortia should broaden their agendas.[21] For example, one participant suggested that collaborative R&D efforts include pre-competitive areas and initiatives to promote vertical integration between suppliers and customers. Some participants argued that U.S. antitrust laws block collaborative activities in areas aside from R&D. Revisions that clarify legal limits on collaboration, specifically for joint production ventures, would be helpful, they suggested.

UNIVERSITY-INDUSTRY COLLABORATION

U.S. universities are an important source of knowledge that supports the technology development process. Although universities account for only 9 percent of public and private research funding in the United States and employ just 10 percent of the nation's scientists and engineers, they conduct approximately 50 percent of the basic research performed in the United States.[22] Since the end of World War II, university research, funded largely by the federal government, has generated new ideas and scientific knowledge that has assisted in the development of industrial products and processes. For more than two decades, university research and the applied R&D and commercialization activities undertaken by industry were able to sustain U.S. leadership in many areas of technology.

In the 1970s, global competition in many industries intensified, and the time to commercialize the results of basic research began to decrease. Foreign competitors became increasingly proficient at converting ideas (some of which were the result of research conducted in U.S. universities) into marketable products. During the 1980s, U.S. firms sought to strengthen relationships with academic researchers, and the number of collaborative ventures between business and universities increased.

Perspectives on University-Industry Collaboration

Industries vary in their motivations for forming research partnerships with universities. Industry perceptions of potential returns, an important influence on whether to collaborate, are driven by a number of factors. These include the specific technical field in which the collaboration occurs, the stage of scientific and technological development within the industry, and whether the research efforts involve basic scientific inquiry or applied R&D. Workshop participants from computer and microelectronics firms, for example, noted that universities are often promising sites for multidisciplinary research ventures involving several firms and teams of university scientists. In contrast, executives from pharmaceutical and biotechnology firms reported that their partnerships with universities were almost exclusively one-to-one collaborations between individual researchers.

Regardless of the industry sector involved, research directors reported that they rely on collaborative research relationships with universities to generate innovative ideas and understanding that might assist long-term corporate R&D strategies.

In contrast to microelectronics firms, companies in the biotechnology and pharmaceutical industries are more likely to view university research as the source of discoveries leading to new products.[23] Firms in biotechnology are likely to allocate larger shares of their R&D budgets to support collaborative ventures with universities than are firms in the more established pharmaceutical industry. In absolute terms, however, large pharmaceutical manufacturers allocate significantly larger amounts of funds to university-based research programs.

Pharmaceutical and Biotechnology Industries

The experiences of major pharmaceutical firms and biotechnology companies, discussed at the workshop, illustrate the variety of strategies and expectations that guide firms' interactions with universities. Pharmaceutical firms often pursue a strategy in which partnerships with universities include many different R&D projects, thereby improving prospects for major discoveries.

Between late 1988 and early 1991, one company formed an average of one new collaboration per month to support its drug discovery efforts. These collaborative ventures were formed in addition to grants to academic investigators and departments, contracts for clinical evaluation of new drugs, and other types of relationships with universities. Collaborators were selected on the basis of careful review, which includes an assessment of how well the goals of the university partners matched the targets specified in the pharmaceutical company's drug discovery portfolio. In biotechnology firms, relationships with universities are often influenced by the industry's strong dependence on basic research conducted by academic and government investigators.

Today, many established and start-up biotechnology firms continue to view universities as a basic research arm, while they devote nearly all of their in-house efforts to applied research. One biotechnology company, for example, funds more than 100 collaborative ventures with universities in the United States, Western Europe, Japan, and Canada. The company also supports academic researchers in areas closely aligned with its product development goals. These projects, however, constitute a small part of its collaborative research arrangements with universities. Company resources are devoted to identifying and licensing the products of university research that have commercial potential. Moreover, it was noted that almost all first-generation biotechnology products, such as human growth hormone and insulin, can be traced to university research.

Through collaborative R&D, firms maintain access to technology developments in academic laboratories. Many therapeutic products were developed by these broad-based research relationships from collaborative ventures with universities, participants noted. In contrast, less product development for pharmaceutical firms has resulted.

Characteristics of Effective Collaboration

Successful collaborative ventures involving industry and universities usually begin with close interaction between personnel in each institution. Several workshop participants indicated that laboratory scientists are more likely to identify the benefits of joint research than company managers and university administrators. Scientists also are more likely to devise specific research plans, participants asserted. One participant advised against negotiating financial and legal details of R&D ventures until scientists have established a tentative research agenda.

Industrial R&D managers have an important role to play in ensuring successful collaboration. Ideally, managers should nurture relationships with academic researchers and their institutions, offer direction for research projects as required, and have their performance evaluated accordingly, one participant noted. Several university and industry representatives strongly urged that those involved in collaborative research set goals at the outset. In contrast to the situation even a few years ago, reported one former university administrator, there is now widespread agreement that academic and industry research partners must agree on technical or scientific tasks to be accomplished. Prospective R&D partners also should attempt to anticipate problems that could undermine the collaborative relationship. Differing views on intellectual property rights and the publication of research results were two frequently mentioned sources of friction.

Issues and Concerns

Workshop participants were in general agreement that collaboration between U.S. firms and universities has the potential to enhance the competitive performance of participating companies. These arrangements can also benefit academic institutions, their faculties, and students. Some participants argued that foreign firms have been more successful than domestic companies in realizing benefits from collaborative R&D involving U.S. universities. Considerable disagreement was expressed during workshop discussions concerning the responsibilities that partners in university-industry ventures should undertake.

Impediments to Negotiations

Companies' experiences in forging collaborative relationships with universities varied widely. Several participants from industry reported that negotiations with university administrators are often protracted and agreement is more difficult to reach than with prospective private sector collaborators. Representatives of small firms, who reported few problems, suggested that the delays encountered by large firms are related to problems with corporate, rather than university, bureaucracies.

The question of intellectual property rights to the discoveries and inventions produced by collaborative ventures elicited considerable debate. An executive of a computer manufacturing firm suggested that when universities enter into intellectual property agreements with businesses, their bargaining position is influenced by past experiences with drug companies. The result can be a "one-size-fits-all" policy for dealing with intellectual property that is not appropriate for all types of R&D. Often, in industries other than pharmaceuticals, patents are cross-licensed between firms and serve as a negotiating point to ensure that each company has access to the other's technology.[24] In contrast, a patent for a new drug confers monopoly power on the owner and therefore is more valuable, warranting royalty payments that might be deemed excessive in other industries.

Other business executives maintained that universities often do not appreciate the considerable expense that companies incur as they go through the many steps involved in converting a discovery into a marketable product. Typically, they said, these costs exceed by at least ten-fold the amount spent on initial research. Moreover, industry executives pointed out, not all discoveries are equivalent. In the case of pharmaceuticals, for example, when a new drug is discovered by the academic partner in a university-industry collaboration, the company is usually granted royalty payments. On the other hand, if company-funded collaborative research yields a new tool or processing method, the sponsoring firm is likely to expect a royalty-free license, although it might allow the university to license the tool or method to other companies.

Not all participants from industry found university procedures for handling intellectual property issues difficult to manage. They reported that university negotiating positions involving technology licensing had not been a significant barrier to collaboration. One university representative maintained that many academic institutions differentiate between types of discoveries and inventions. Most also recognize that the value of patent protection varies among industries, he argued. Several academic officials noted that universities are working to develop approaches for negotiating intellectual property rights that take institutional differences into account. Conflicts over intellectual property rights have, however, presented barriers to successful university-industry cooperative ventures.

Access for Small Firms

Small firms often have limited resources, research capacity, or experience with collaborative ventures. Some participants at the workshop noted that these problems are associated with small firms' difficulties in forming R&D partnerships with universities. As a consequence, one speaker asserted, only large companies have access to discoveries and inventions arising from university-based research. While acknowledging the need to be alert to this concern, participants from pharmaceutical and biotechnology companies reported that small firms appear to have access to university research and its products. One participant noted that, in some cases, small firms succeed in licensing a university-owned invention but then lack the resources to carry out the work necessary to bring the product to market.

Commitment of U.S. Firms

Some industry participants questioned the commitment that domestic firms make to collaborative ventures with universities. It was noted that foreign firms appear to benefit to a greater degree than U.S. companies from partnerships with U.S. academic institutions. One research director for a major U.S. multinational firm maintained that American companies typically do not bring the same level of dedication, diligence, and interest to university-industry collaborations as do their foreign counterparts.

An executive from a foreign-based multinational firm maintained that foreign firms do not enjoy preferential access to U.S. university-based research. Rather, he reported, European and Japanese firms more fully recognize that they have an obligation when they enter into relationships with universities. That is, the foreign firms realize that they must bring innovative ideas to the collaboration and that it is their responsibility to take and use discoveries or inventions that result from it.

One speaker suggested that U.S. firms may be more diligent partners in the growing number of relationships they are forming with research institutions in other countries. This may result, in part, from the greater effort required by U.S. companies to cultivate ties with unfamiliar overseas partners.

Conflict of Interest and Public Perceptions

Real and perceived conflicts of interest can present obstacles to collaborative relationships between universities and industry.[25] Potential conflicts are common, according to one university representative, and the challenge for both parties is to manage them appropriately. One set of concerns involves the level of financial compensation for products resulting from research conducted at universities. Some participants argued that research supported by the government should mean that the results of such research are publicly available. Conflict may also arise when university faculty serve as consultants to industry, an activity viewed by some as in conflict with education goals.

Moreover, the question of whether foreign firms should have access to the results of research conducted at U.S. universities continues to be debated. This concern reflects the larger issue of foreign participation in U.S.-based collaborative ventures and, conversely, the participation of U.S. firms in foreign R&D ventures.

GOVERNMENT-INDUSTRY COLLABORATION

The government accounts for nearly half of the total R&D spending in this country. It is the nation's largest single employer of scientists and research engineers and provides funding for most basic research conducted by universities. In addition, the more than 700 federal laboratories employ nearly one-sixth of the scientists in the United States. Defense R&D constitutes a large percentage of the total federal R&D budget, accounting for more than 60 percent of such expenditures during the last decade.

Some policy analysts and business leaders have suggested that U.S.-economic interests would be better served if the government assumed a broader and more active role in civil technology development. One industry executive at the workshop noted that many of the "critical technologies" identified by various groups will probably not contribute to the nation's defense. Yet progress in many of these key areas, he argued, is crucial to the performance of many U.S. industries, to national economic performance, and to improvement in the U.S. standard of living.

Since the late 1970s, the federal government has provided incentives to encourage the transfer technology from federal laboratories to the private sector; it established SEMATECH, created NSF Engineering Research Centers, and established the Advanced Technology Program at the National Institute of Standards and Technology.

The ATP is centered on the development of pre-competitive, generic technology with significant commercial promise.[26] In fiscal year 1991, ATP awarded some $9 million to support 11 industry-led R&D projects in such areas as x-ray lithography for semiconductor manufacturing, high-temperature superconductivity, flat-panel display manufacturing, and optical recording.[27]

Federal Laboratory-Industry Collaboration

There is considerable debate about the utility of federal initiatives, the most productive modes of collaboration, and the need for a national policy for technology transfer.[28] Participants at the workshop discussed the fact that technology transfer requires sustained, market-driven technology programs. As one laboratory director explained, early technology transfer efforts were guided by the mistaken assumption that federal scientists and engineers had created a vast wealth of technology with commercial applications. Measures to improve private sector access to the laboratories, it was believed, would yield a stream of off-the-shelf technologies that could easily be converted to commercial applications. That has not been the case, several participants noted. Most of the technology at the federal laboratories, according to one participant, was developed to support the missions of federal agencies rather than to address commercial needs. In recent years, Congress has passed measures to create incentives for laboratory-industry collaboration and technology transfer. For example, federal scientists and engineers can now collect royalties on patented inventions they create.[29] Procedures for licensing federal technology have been simplified, and industry sponsors of collaborative research conducted at national laboratories can own or secure exclusive licensing rights to inventions arising from these joint efforts. Nonetheless, the missions of many of the federal laboratories do not reflect the commercial technology needs of industry. One participant noted that the NIST is the only federal facility with the explicit mission of assisting U.S. industry.

Some federal agencies that conduct research are taking steps to foster collaborative relationships with industry. The Department of Energy, for example, has explicitly included technology transfer in the mission statement of each of its laboratories.[30] DOE laboratories are now evaluated on the basis of how successfully they work with industry. In addition, the department's decisions on investments in capital and equipment are guided by its desire to make the laboratories better partners with industry. Another participant noted, however, that mission statements can be changed easily. Other, more difficult changes—in facilities, staff, and location—will be needed if federal laboratories are to fulfill a role in technology development and transfer, they noted.

SEMATECH

SEMATECH's goal is to develop a domestic capacity for world-class levels of semiconductor manufacturing by 1993. The federal government supplies half of the consortium's $200 million annual budget; SEMATECH's 14 member companies provide the remaining funds. The five-year experiment conducts in-house research and funds outside R&D projects. In recent years, SEMATECH has spent a growing portion of its budget on R&D projects conducted by a group of 140 equipment and materials manufacturers that make up the consortium's fifteenth member, SEMI/SEMATECH. These outside R&D projects now comprise half of SEMATECH's research budget. SEMATECH provides about 10 percent of the funding for equipment improvement projects and about 30 percent of the support for joint development projects focusing on new equipment. Collaborating companies provide the rest. The consortium also funds research at its 11 university-based centers of excellence and at several national laboratories. In-house research is carried out by the consortium's 700-person staff, one-third of whom are on loan from corporate members.

In addition to its research program, SEMATECH is working to improve relationships between semiconductor manufacturers and domestic suppliers. For example, SEMATECH's corporate members conduct qualification tests of new equipment at a single site. Representatives from other firms come to the test site, where they evaluate equipment performance and provide feedback to the supplier.[31]

Anticipated Returns

Workshop participants noted that the consortium appears to be achieving its technical goals on schedule. By mid-1993, the end of its original five-year charter, SEMATECH is expected to reach its goal of producing memory chips with 0.35-micron circuitry at its pilot fabrication plant in Austin, Texas, using equipment from domestic U.S. suppliers. One speaker predicted that with SEMATECH's contributions, U.S. semiconductor manufacturers and their suppliers will reach parity with the Japanese in equipment and some processes by 1993. Some participants argued that the United States should have firms capable of producing world-class quality equipment for each stage in the semiconductor manufacturing process: lithography, furnaces and implantation, etching, planarization, and deposition.

Some participants at the workshop reported that semiconductor manufacturers are benefiting from the consortium's programs. For example, two firms have used technical information from SEMATECH's pilot fabrication facility to guide planning of new manufacturing plants. Other participants have used SEMATECH's technical expertise to guide the purchase of new equipment. Workshop participants discussed plans for SEMATECH after 1993, when its initial five-year authorization ends. Some suggested that current SEMATECH programs could be extended to new areas of manufacturing. One such possibility, a participant noted, is "clean sheet" designs for factories built to manufacture the next generation of high-density memory and logic chips. SEMATECH might also be used to compare the advantages of costly, large-scale production facilities with the benefits that might be achieved from small fabrication plants.

Government-Sponsored R&D Collaboration in Other Countries

Government-led collaborative R&D efforts in other nations have received significant attention.[32] Collaborative programs in Europe were discussed at the workshop. The changing nature of Japan's collaborative R&D programs was also discussed, as programs that initially focused on applied R&D projects increasingly emphasize basic science and engineering.[33]

The European Community

The long-term research programs jointly sponsored by the governments and businesses of the European Community (EC) are an expression of Europe's emphasis on new technology.[34] According to one participant, these R&D projects also reflect the recognition that technology development requires substantial economic support, that the scale of the required efforts often outstrips the capacities of individual companies and nations, and that the globalization of technology shortens technical advantages. Many European firms view collaborative R&D as a way to achieve a competitive edge. This widely held perception distinguishes European companies from their American counterparts, which are more likely to pursue individual R&D initiatives exclusively with internal resources.

Many of the barriers to collaborative R&D that European nations are working to overcome, such as cultural and language differences and competing national interests, do not inhibit U.S. collaborative ventures. While acknowledging that transnational collaborations can lead to administrative confusion and the waste of resources, several participants asserted that European countries have built a viable framework for collaborative R&D. EC nations have forged a consensus on the technological areas most vital to future industrial competitiveness and are allocating their R&D support accordingly.

Japan

Government-led cooperative R&D in Japan has evolved through three stages since 1950. During the 1950s and 1960s, the country's efforts focused on creating the science and engineering foundation for economic development. Initially, government support for R&D was directed to individual firms, which contributed between 50 and 70 percent of project funds.

To stimulate research efforts, some participants noted, the government created a network of trade organizations, the Engineering Research Associations. With government support and guidance, the associations organized collaborations among small and midsize companies to address common technical barriers. Industrial trade associations remain an important feature of collaborative R&D in Japan. During the 1970s, the focus of government-led collaborations changed. Efforts were directed at elevating the performance of Japanese companies in technology generation. Collaborative projects were designed to refine advanced technologies. The specific goals of each collaborative venture were developed by the government in close consultation with the trade associations.

The third stage of Japan's government-led collaborative R&D efforts came as Japanese companies began to dominate world markets for many high-technology consumer products. This current phase of Japanese government-industry research focuses on the development of next-generation technologies. One recent initiative is the government-funded Key Technology Center (KTC) program, which has provided support for more than 60 projects since 1985.

The Key Technology Center (KTC) Program

In contrast to earlier initiatives focused on next-generation technology, the KTC program involves high-risk R&D. The program functions as a venture capital fund, providing seed money in the form of government-owned equity shares to support industrial collaborations, which typically involving 10 or fewer companies. (Participation of foreign-owned subsidiaries in KTC programs is not prohibited.) Participants are expected to produce commercially useful technology and to operate profitably over a seven-to ten-year period.

The Optoelectronic Technology Research Corporation (OTRC) is an example of this new approach to cooperative R&D. Founded in 1986, the center has 13 member companies and an annual budget of about $7.5 million, 70 percent of which is supplied by the Japanese government. OTRC's research agenda is the product of a planning process involving member companies, government, and universities. The goal of the center's research program is to develop the knowledge and tools to design and manufacture integrated circuits that combine electronic and photonic technologies.[35] Optoelectronic integrated circuits are expected to be important components of future communications and computing equipment. R&D work at OTRC is divided between the center's laboratory in Tsukuba Science City, outside Tokyo, where 20 scientists focus on process-related issues, and the in-house laboratories of member firms, where collectively some 30 researchers work on various devices and applications.

Technology transfer between member firms is promoted by the dissemination of reprints of articles and other presentations by center scientists, an annual workshop for company representatives, and semiannual panel discussions in which government and university scientists also participate. To date, the center's R&D work has not produced any inventions that have resulted in patents. Should patented technologies result from the research, decisions on licensing the inventions to nonmember firms will be made on a "case-by-case basis." Rights to patented inventions, however, are assigned to the member firms, not the government.

Issues for Consideration

Several workshop participants suggested criteria for evaluating the merits of proposed collaborative ventures and defining the roles of prospective partners. Two criteria that might be used to select areas of collaboration are (1) high levels of technical and financial risk and (2) a chance of high returns for successful ventures. Without the incentive of profit, individual businesses will not undertake R&D on potentially risky projects.

There are other mechanisms by which technologies developed through government-supported collaborations can lead to product refinement and commercialization. A clear lesson of the past, participants noted, is the need to pull technology from R&D ventures. Historically, an industry representative noted, government-funded projects have been operated under the assumption that technology will flow to industry, which will then commercialize the product or process application. As was noted often throughout the workshop, however, this expectation leads to less than successful technology transfer outcomes.

One participant noted that the government will need a way to assess the "value added" by each prospective partner in a collaboration. The personnel and technical contributions of collaborating firms must enhance prospects for achieving project goals and, ultimately, the technological advantage that motivated the cooperative effort. Moreover, steps must be taken to ensure the participation of small companies, an important source of new ideas and innovations. Government loans or loan guarantees might be used to encourage innovative small companies to participate in cooperative projects. In addition, it was suggested, carefully crafted tax incentives might encourage large U.S. companies to assist smaller businesses as they work to develop new technologies and products. Finally, many participants recommended that collaborative projects should be required to meet a series of technical milestones and should be monitored periodically for progress.

Participation of Foreign Companies

As participants noted, it is increasingly difficult to distinguish between U.S. and foreign companies. Just as U.S.-based firms have subsidiaries overseas, foreign corporations have operations in the United States that employ U.S. workers and provide federal and state tax revenue. Some public and private sector representatives at the workshop suggested that if a foreign-owned U.S. subsidiary pays taxes in the United States, it should be eligible to participate in government-supported R&D collaborations. It was also noted that foreign participation in collaborative research can benefit U.S. companies. In many key areas, workshop participants said, foreign firms are at the forefront of technological know-how. To be competitive, U.S. companies must draw on these repositories of expertise.

NOTES

1. For an overview of methods to promote development in small firms, see P. Shapira, "Helping Small Manufacturers Modernize," *Issues in Science and Technology* 7(Spring 1990): 49-54.
2. See Stephen J. Kline and Nathan Rosenberg, "An Overview of Innovation," in *The Positive Sum Strategy,* eds. Ralph Landau and Nathan Rosenberg (Washington, D.C.: National Academy Press, 1986) and David C. Mowery, "The Diffusion of New Manufacturing Technologies," in *The Impact of New Technologies on Employment and Economic Growth*, eds. Richard M. Cyert and David C. Mowery (Cambridge, Mass.: Ballinger, 1987).
3. For an overview of the innovation process, see Stephen J. Kline, *Models of Innovation and Their Policy Consequences*, Report INN-4B (Stanford University, Stanford, California, 1990).
4. See Wendy Schacht, *Commercialization of Technology and Issues in the Competitiveness of Selected U. S. Industries: Semiconductors, Biotechnology, and Superconductors* (Paper prepared for the Congressional Research Service, Washington, D.C., 1988).
5. For an overview of some of these difficulties see The President's Council on Competitiveness, *Report on National Biotechnology Policy* (Washington, D.C., 1991).

6. See, for example, U.S. Department of Commerce, *Federal Government Initiatives with Policy Implications for Science and Technology* (Washington, D.C.: U.S. Government Printing Office, 1988).

7. See U.S. Congress, House Committee on Small Business, Subcommittee on Regulation, Business Opportunities, and Energy, *Hearing on Technology Transfer Obstacles in Federal Laboratories: Key Agencies Respond to Subcommittee Survey*, 101st Cong., 2nd sess., 1990.

8. For an overview of DOE technology transfer efforts, see U.S. Congress, House of Representatives, *DoE's Enhanced Technology Transfer Program* , statement of W. Henson Moore, Deputy Secretary, Department of Energy and testimony of Matthew B. Coffey, president, National Tooling & Machining Association, at a hearing before the Committee on Energy and Commerce, Subcommittee on Oversight and Investigations, 102nd Cong., 1st sess., July 25, 1991.

9. For an overview of the program see U.S. Department of Commerce, National Institute of Standards and Technology, "Procedures for the Selection and Establishment of NIST Manufacturing Technology Centers," Part 290, Title 15, *Federal Register* (September 17, 1990):8.

10. The Omnibus Trade and Competitiveness Act (P.L. 100-418), section 5131 authorized the creation of the Advanced Technology Program.

11. For a discussion of regional economic development and the role of states in promoting industrial development, see R. Scott Fosler, ed., *The New Economic Role of the States: Strategies in a Competitive World Economy* (New York: Oxford University Press, 1988).

12. For an overview of state technology transfer efforts, see M. K. Clarke and E. N. Dobson, *Promoting Technology Excellence: The Role of State and Federal Extension Activities* (Washington, D.C.: National Governors Association, 1989).

13. See Ben Franklin Partnership Board, *48-Month Progress Report, March 1, 1983-February 28, 1987* (Philadelphia: Pennsylvania Technology Assistance Program, Ben Franklin Partnership Challenge Grant Program for Technological Innovation, 1987), and other reports of the Ben Franklin Partnership Board.

14. Center for Social and Economic Issues, Industrial Technology Institute, Solomon Associates, and J. D. Eveland, *Literature of Collaborative Research and Development: An Analytic Overview* (Report submitted to the Congressional Office of Technology Assessment, U.S. Congress, 1986).

15. For a brief overview of cooperative R&D efforts in the United States, see H. I. Fusfeld and C. S. Haklish, "Cooperative R&D for Competitors," *Harvard Business Review* (November-December 1985): 60-76, and John A. Alic, "Cooperation in R&D," *Technovation* 10, no. 5 (1990): 319-331.

16. For an overview of forces impacting global technology development and strategic technology alliances, see National Academy of Engineering, *National Interests in an Age of Global Technology* (Washington, D.C.: National Academy Press, 1991), and John Hagedoorn and Jos Schakenraad, *Strategic Partnering and Technological Cooperation* (The Netherlands: Maastricht Economic Research Institute on Innovation and Technology, 1989).

17. Jerry Werner and Jack Bremer, "Hard Lessons in Cooperative Research, *Issues in Science and Technology* (Spring 1991): 44-49.

18. See B. Bozeman, A. Link, and A. Zardkoohi, "An Economic Analysis of R&D Joint Ventures," *Managerial and Decision Economics* 7 (1986): 263-266, as cited in David Mowery, *Collaborative Research: An Assessment of Its Potential Role in the Development of High Temperature Superconductivity* (Report prepared for the Office of Technology Assessment, U.S. Congress, 1988).

19. See National Research Council, Office of Japan Affairs, *R&D Consortia and U.S.-Japan Collaboration* (Washington, D.C., 1991), 16.

20. U.S. Congress, General Accounting Office, *SEMATECH's Efforts to Strengthen the U.S. Semiconductor Industry* (Washington, D.C., 1990).

21. There have been several bills introduced in Congress to remove antitrust restrictions on cooperative manufacturing and production ventures. These include, H.R. 4611 and S. 1006. H.R. 4611, *National Cooperative Production Amendments of 1990,* sponsored by Congressman Brooks, amends the National Cooperative Research Act of 1984 to reduce the liability for joint ventures entered into for the purpose of producing a product, process, or service. It also excludes from qualification any joint venture over 30 percent foreign investors, and requires that production facilities be located in the United States. S. 1006, *National Cooperative Research Act Extension of 1989,* sponsored by Senator Leahy, is similar to H.R. 4611, although the bill did not include the foreign exclusion provision or facilities location requirements in H.R. 4611. The administration supported the Senate bill.

22. For an overview of the U.S. university research enterprise, as well as that in other industrialized nations, see National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *The Academic Research Enterprise within the Industrialized Nations: Report of a Symposium* (Washington, D.C.: National Academy Press, 1990).

23. For an overview of collaborative research in pharmaceutical and biotechnology, see Kathi Hanna, "Collaborative Research in Biomedicine," in *Government and Industry Collaboration in Biomedical Research and Education, Report of a Workshop*, Institute of Medicine (Washington, D.C.: National Academy Press, 1989).

24. For an overview of policy issues affecting the information technology sector, including intellectual property rights protection and licensing agreements, see Ken Guy and Erik Arnold, *A Review of Policies Affecting the IT [Information Technology] Sectors of the USA, Japan, EEC, France, West Germany, and the UK* (Science Policy Research Unit, University of Sussex, United Kingdom, 1987).

25. For an overview of these issues, see J. A. Nowack, "The University Policy Environment for University-Industry Interactions," in *Government and Industry Collaboration in Biomedical Research and Education: Report of A Workshop*, Institute of Medicine (Washington, D.C.: National Academy Press, 1989).

26. For a discussion of the administration's view of the government role in civilian technology, see "Testimony of the Honorable D. Allan Bromley," Director of the Office of Science and Technology Policy, Executive Office of the President, before the U.S. Senate Committee on Commerce, Science, and Transportation, May 23, 1990, and Office of Science and Technology, *Technology Policy* (Office of the President, Washington, D.C., 1990).

27. U.S. Department of Commerce, "Mosbacher Announces Eleven Grants to Advance Key Industrial Technologies" (Press release, Washington, D.C., March 5, 1991).

28. For an overview of issues concerning technology transfer from the federal laboratories to industry, see U.S. Congress, House Committee on Small Business, Subcommittee on Regulation, Business Opportunities, and Energy, 101st Cong., 2nd sess., *Technology Transfer Obstacles in Federal Laboratories: Key Agencies Respond to Subcommittee Survey* (Washington, D.C.: U.S. Government Printing Office, 1990) and U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Science, Research, and Technology, 101st Cong., 2nd sess., *Transfer of Technology from the Federal Laboratories* (Washington, D.C.: U.S. Government Printing Office, 1990).

29. The public laws which direct federal technology transfer policy, including incentives to researchers to commercialize federal technology include P.L. 96-480 Stevenson-Wydler Technology Innovation Act of 1980, P.L. 96-517 Government Patent Policy Act of 1980, and P.L. 99-502 Federal Technology Transfer Act of 1986.

30. J. F. Decker, "The Office of Energy Research's Approach to Improved Technology Transfer" (Paper presented at the Department of Energy Transfer Orientation Seminar, U.S. Department of Energy, Office of Energy Research, Washington, D.C., January 24, 1991).

31. For an overview of SEMATECH and progress to date, see U.S. Congressional Budget Office, *The Benefits and Risks of Federal Funding of SEMATECH* (Washington, D.C.: U.S.

Government Printing Office, 1987) and U.S. Congressional Budget Office, *Using R&D Consortia for Commercial Innovation: SEMATECH, X-Ray Lithography, and High Resolution Systems* (Washington, D.C.: U.S. Government Printing Office, 1990), among other reports.

32. For an overview of technology policy overseas, and role of collaborative R&D programs, see Henry Ergas, "Does Technology Policy Matter?", in *Technology and Global Industry*, eds. Bruce R. Guile and Harvey Brooks (Washington, D.C.: National Academy Press, 1987) and Richard R. Nelson, *High-Technology Policies: A Five Nation Comparison* (Washington, D.C.: American Enterprise Institute, 1984).

33. Battelle Memorial Institute, *Government-Promoted Collective Research and Development in Japan: Analyses of the Organization Through Case Studies* (Washington, D.C.: Pacific Northwest Laboratory, 1990).

34. See Delegation of the Commission of the European Communities, "Important Progress for European Community Research," (Brussels, Commission of the European Communities, 1990).

35. Optoelectronics Technology Research Laboratory, *Technology for the 21st Century* (Program Description, Optoelectronics Technology Research Laboratory, Tsukuba Science City, Japan, 1990).

APPENDIX B

Legislative Request for the Study

OMNIBUS TRADE AND COMPETITIVENESS ACT (P.L. 100-418)

"(2) The Committee shall render to the Secretary and the Congress such additional reports on specific policy matters as it deems appropriate.

"(c) NATIONAL ACADEMIES OF SCIENCES AND ENGINEERING STUDY OF GOVERNMENT-INDUSTRY COOPERATION IN CIVILIAN TECHNOLOGY.—

"(1) Within 90 days after the date of enactment of this Act, the Secretary of Commerce shall enter into contracts with the National Academies of Sciences and Engineering for a thorough review of the various types of arrangements under which the private sector in the United States and the Federal Government cooperate in civilian research and technology transfer, including activities to create or apply generic, nonproprietary technologies. The purpose of the review is to provide the Secretary and Congress with objective information regarding the uses, strengths, and limitations of the various types of cooperative technology arrangements that have been used in the United States. The review is to provide both an analysis of the ways in which these arrangements can help improve the technological performance and international competitiveness of the United States industry, and also to provide the Academies' recommendations regarding ways to im prove the effectiveness and efficiency of these types of cooperative arrangements. A special emphasis shall be placed on discussions of these subjects among industry leaders, labor leaders, and officials of the executive branch and Congress. The Secretary is authorized to seek and accept funding for this study from both Federal agencies and private industry.

"(2) The members of the review panel shall be drawn from among industry and labor leaders, entrepreneurs, former government officials with great experience in civilian research and technology, and scientific and technical experts, including experts with experience with Federal laboratories.

"(3) The review shall analyze the strengths and weaknesses of different types of Federal-industry cooperative arrangements in civilian technology, including but not limited to—

"(A) Federal programs which provide technical services and information to United States companies;

"(B) cooperation between Federal laboratories and United States companies, including activities under the Technology Share Program created by Executive Order 12591;

"(C) Federal research and technology transfer arrangements with selected business sectors;

"(D) Federal encouragement of, and assistance to, private joint research and development ventures; and

"(E) such other mechanisms of Federal-industry cooperation as may be identified by the Secretary.

"(4) A report based on the findings and recommendations of the review panel shall be submitted to the Secretary, the President, and Congress within 18 months after the Secretary signs the contracts with the National Academies of Sciences and Engineering.

CONGRESSIONAL RECORD-HOUSE SECTION 5131(C)

"National Academies of Science and Engineering Study of Government-Industry Cooperation in Civilian Technology

Present Law

"No provision.

House Bill

"No provision.

Senate Amendment

"Specifies that the Director may contract periodically with the Academies to receive advice and studies on the nation's significant national needs and opportunities in manufacturing and emerging technologies. The bill specified the responsibilities of the review panel of the Academies.

Conference Agreement

"The Conferees agree to accept the Senate proposal authorizing the Secretary of Commerce to contract with the Academies, including the Institute of Medicine, for a review of the various types of arrangements under which the private sector in the United States and the Federal Government cooperate in civilian research and technology and technology transfer. Panelists are to be drawn from a broad spectrum of backgrounds and the Academies should also draw on the expertise of its Board of Assessments for NIST. The purpose of the review is to provide the Secretary of Commerce and the Congress with objective information regarding the uses of the various types of cooperative technology arrangements currently being applied in the United States, as well as a candid assessment of which of these arrangements work well and what conditions are necessary for them to work. The Conferees note that there have been a sizable number of programs set up legislatively and administratively over the past decade and feel that there should be enough experience from the initial experiments under these programs for the Academies to reach some conclusions regarding effectiveness and to make recommendations for improvement. The Conferees feel that this study will help guide the government properly to invest in the most promising of these alternatives. The proposal supersedes studies by the Academies under the Semiconductor and Superconductor Research section of the Technology Reviews in Title XLIII of the Senate bill. The Secretary of Commerce is to seek funding for this review from other federal agencies and private industry. A report is to be submitted to the Secretary of Commerce, the President, and the Congress within eighteen months after the contracts are signed with the Academies."

APPENDIX C

Workshop Presenters and Briefers to the Panel

Workshop on "THE DIFFUSION OF INNOVATIVE TECHNOLOGIES: LESSONS OF SUCCESS" THE GOVERNMENT ROLE IN CIVILIAN TECHNOLOGY PROJECT April 19-20, 1990

PRESENTERS

Reid G. Adler, Director of Technology Transfer, National Institutes of Health

Arnold L. Bement, Jr., Vice President of Technical Resources, TRW, Inc.

Harvey J. Berger, President of Research & Development Division, Centocor, Inc.

Jeff Bingaman, Chairman, Defense Industry & Technology Subcommittee, Armed Services Committee, U.S. Senate

Samuel H. Fuller, Vice President of Research, Digital Equipment Corporation

Joseph Gormley, Director of Electrical/Electronic Systems Engineering Office, Ford Motor Company

Donald A. Hicks, Professor of Political Economics, Bruton Center for Development Studies, University of Texas at Dallas

William G. Howard, Jr., Senior Fellow, National Academy of Engineering

Cherri J. Langenfeld, Acting Director, Office of Technology Policy, U.S. Department of Energy

John W. Lyons, Director of National Institute of Standards and Technology, U.S. Department of Commerce

Alexander MacLachlan, Senior Vice President of Technology, DuPont Company

John S. Mayo, Senior Vice President of Network Systems and Network Services, AT&T Bell Labs

Edward A. Miller, President, National Center for Manufacturing Sciences

Parviz Mokhtari, Corporate Vice President and Assistant General Manager, Automotive and Industrial Electronics Group, Motorola, Inc.

Thomas J. Murrin, Deputy Secretary of Commerce, U.S. Department of Commerce

Walt Plosila, President of Montgomery County High-Technology Council

Niels Reimers, Acting Director of Office of Technology Licensing, University of California at Berkeley

William Ribbens, Electrical Engineering and Computer Sciences Department, University of Michigan

James Sherblom, Transgenic Sciences, Inc.

Jack Simon, Advanced Manufacturing Engineering, General Motors Corporation

H. Guyford Stever, Corporate Director and Science Advisor

David H. Swanson, Economic Development, Georgia Tech Research Institute

Robert A. Weinberg, Whitehead Institute, Massachusetts Institute of Technology

James B. Wyngaarden, Office of Science and Technology Policy, Executive Office of the President

Gerold Yonas, Director of Laboratory Staff, Sandia National Laboratories

Workshop on "RESEARCH AND DEVELOPMENT CONSORTIA: MYTH AND REALITY" THE GOVERNMENT ROLE IN CIVILIAN TECHNOLOGY PROJECT AND THE ACADEMY INDUSTRY PROGRAM

March 26-27, 1991

PRESENTERS

John A. Armstrong, Vice President of IBM Corporation

Harvey J. Berger, M.D., Chairman and CEO, ARIAD Pharmaceuticals, Inc.

Frank P. Carrubba, Director of Hewlett-Packard Laboratories, Hewlett-Packard Company

John M. Deutch, Institute Professor, Massachusetts Institute of Technology

Craig I. Fields, President and CEO Microelectronics and Computer Technology Corporation

Kenneth Flamm, Senior Fellow, The Brookings Institution

Robert W. Galvin, Chairman of the Executive Committee, Motorola

Gregory Gardiner, Director, Research Operations, Pfizer Central Research, Pfizer, Inc.

Kiyoshi Hasegawa, Executive Director, Optoelectronics Technology Research Corporation

John W. Lyons, Director, National Institute of Standards and Technology

Robert M. Price, Retired Chairman and CEO, Control Data Corporation

William J. Spencer, President and CEO, SEMATECH

Karl H. Zaininger, President and CEO, Siemens Corporate Research, Inc.

INDIVIDUAL BRIEFINGS

RICHARD BERNSTEIN, Defense Intelligence Agency

PETER CANNON, President and CEO, Conductus, Inc.

MITCHELL DOSSETT, Defense Intelligence Agency

IRWIN FELLER, Pennsylvania State University

CARY GRAVATT, National Institute of Standards and Technology

RONALD KELLER, Defense Intelligence Agency

VICTOR REIS, Director, Defense Advanced Research Projects Agency

WILLIAM RUTTER, Chairman, Chiron Corporation

JOHN B. TAYLOR, Council of Economic Advisors, Executive Office of the President

JOHN WARNER, Vice President, Boeing Commercial Airplane Group

ROBERT M. WHITE, Undersecretary of Commerce for Technology, U.S. Department of Commerce

LEO YOUNG, U.S. Department of Defense

APPENDIX D

Biographical Information on Panel Members and Professional Staff

PANEL MEMBERS

HAROLD BROWN, *Chairman,* is Chairman of the Foreign Policy Institute of the Johns Hopkins University School of Advanced International Studies. He also serves as a member of the Board of Directors of IBM, CBS, and Cummins Engine Company, among other companies. Dr. Brown was Secretary of Defense from 1977 until 1981. From 1969 until 1977, he was President of the California Institute of Technology. Dr. Brown served as Director of Defense Research and Engineering from 1961 to 1965. He subsequently became Secretary of the Air Force, a post he held until 1969. Before beginning his Defense Department work in 1961, Dr. Brown had been Director of the Radiation Laboratory at Livermore, University of California and a member of the President's Science Advisory Committee.

JOHN A. ARMSTRONG is Vice President and Director of Research for IBM. In 1989, he was elected to the Corporate Management Board. Since joining IBM in 1963, he has held several positions within the company's research laboratories, including Director of Physical Sciences and Manager of Materials and Technology Development. Previously he was Chairman of the Advisory Board for Physics of the National Science Foundation. In 1987, Dr. Armstrong was elected a member of the National Academy of Engineering and the Royal Swedish Academy of Engineering Sciences. Dr. Armstrong has written or co-authored more than 50 scientific papers on the subjects of nuclear resonance, nonlinear optics, the statistical properties of laser light, picosecond pulse measurements, and the multiphoton laser spectroscopy of atoms.

HARVEY J. BERGER is presently Chairman and Chief Executive Officer of ARIAD Pharmaceuticals and a specialist in cardiovascular and diagnostic imaging. Dr. Berger is the author of more than 200 contributions to scientific literature. He is a former Executive Vice President and Medical Director and Research and Development chief of Centocor, Inc., a biotechnology firm. Dr. Berger is also an Adjunct Professor at the University of Pennsylvania School of Medicine. Previously, he was Professor of Radiology and Medicine and a Division Director at Emory University School of Medicine in Atlanta. Dr. Berger is a founding member of the University Technology Transfer Consortium, a multidisciplinary group established to facilitate commercial development of inventions originating in Delaware Valley academic institutions.

C. FRED BERGSTEN is Director of the Institute for International Economics, a position he held since the institute's creation in 1981. From 1980 to 1981 he functioned as Under Secretary for Monetary Affairs; from 1977 to 1981 he was Assistant Secretary of the Treasury for International Affairs; and from 1969 to 1971 he served as assistant for International Economic Affairs on the Senior Staff of the National Security Council. Dr. Bergsten has been a senior fellow at the Brookings Institution, the Carnegie Endowment for International Peace, and the Council on Foreign Relations. He has written 18 books and numerous articles on international economic issues.

WILLIAM F. BRINKMAN is Executive Director of Physics Research at AT&T Bell Laboratories. His responsibilities include the direction of research in condensed matter physics and optoelectronic devices. Among the other positions he has held at Bell Labs were chief of the Physical Research Laboratory, the Chemical Physics Research Laboratory, and Infrared Physics and Electronics Research. Prior to his current position, he was Vice President of Research at Sandia National Laboratories in Albuquerque. He has served on a number of national committees, including chairmanship of the National Academy of Sciences Physics Survey and its Solid-State Sciences Committee. He was elected a member of the National Academy of Sciences in 1984.

DENNIS CHAMOT is Executive Assistant to the President, Department of Professional Employees of the AFL-CIO. He was Assistant to the Executive Secretary, Council of AFL-CIO Unions for Professional Employees beginning in 1974, became Assistant Director of the AFL-CIO's Department for Professional Employees in 1977 and its Associate Director in 1984. He has been a member of numerous study panels including congres sional studies of workplace automation and the National Research Council's Committee on Computer-Aided Manufacturing. He also served as chairman of the National Science Foundation's Informal Science Education Oversight Committee. Dr. Chamot was employed by E.I. DuPont de Nemours as a research chemist from 1969 to 1973.

RICHARD N. COOPER is Maurits B. Boas Professor of International Economics at Harvard University, where he has lectured since 1981. Professor Cooper previously served as Provost and Professor of International Economics at Yale University. From 1977 to 1981 he was Under Secretary for Economic Affairs in the U.S. Department of State, from 1965 to 1966 Deputy Assistant Secretary of State for International Monetary Affairs, and from 1961 to 1963 Senior Staff Economist for President Kennedy's Council on Economic Advisors. Professor Cooper is presently Chairman, Federal Reserve Bank of Boston; Director and Advisory Committee Chairman, Institute for International Economics. He is the author of numerous books on economic policy.

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APPENDIX E

Collaborative R&D: Selected Examples

University-Industry Cooperative R&D. The traditional focus of R&D cooperation between academia and industry has centered on basic research. Industry views universities as important sources of basic scientific research and technical information that complement in-house R&D capabilities. Universities can gain important insight into industry R&D efforts and financial support for ongoing research through joint R&D efforts. Both parties have the potential to benefit from corporate involvement in support of student training. Joint university-industry projects expose students in science and engineering programs to industrial research and development. These ventures may also offer firms the opportunity both to recruit future employees and to make use of on-campus consulting expertise. Although university-industry collaboration may provide benefits to both parties, there are potential difficulties with this type of R&D cooperation, including problems associated with balancing university basic research objectives with proprietary R&D work for individual firms.

Examples of university-industrial cooperation are the industry-university cooperative research centers of the National Science Foundation (NSF). More than 50 universities now have cooperative research centers that emphasize fundamental engineering and scientific research with industrial applications. Most funding comes from fees assessed industry members. State governments, federal laboratories, and nonprofit organizations also participate in the centers. Another NSF program is that of the Engineering Re search Centers (ERCs) located at 18 academic research institutions. The ERCs engage in multidisciplinary engineering research and are funded by industry, NSF, and state and local governments.

The decentralized nature of university research has made links between industry and academia an attractive option for regional initiatives. The North Carolina Microelectronics Center, for example, fosters cooperation in computer manufacturing.

Private Sector Collaborative Ventures. A wide range of cooperative R&D mechanisms were employed by U.S. industry. Most collaborative projects involve joint activity without direct government involvement. Moreover, participation in joint R&D is initiated for many reasons. Greater competition from innovative foreign producers, for example, has prompted some U.S. companies to seek the technological synergies of industry-wide cooperation. Other motives include the desire to lower R&D costs, to monitor the capabilities of rival firms, and to learn state-of-the-art manufacturing techniques.

Most discussion of collaborative R&D has focused on joint research efforts in R&D-intensive, high-technology industries such as microelectronics. Collaborative R&D projects have also been formed by a number of utilities and in traditional industries as well. The Textile/Clothing Technology Corporation and National Apparel Technology Center, for example, have been established to work on product and process technologies in the textile and apparel complex.

One way in which the government has attempted to foster collaborative ventures is through relaxation of antitrust restrictions on cooperative R&D through the National Cooperative Research Act (NCRA) of 1984. It is generally assumed that this law has helped to stimulate the formation of private consortia. One of the first ventures formed under NCRA is the Microelectronics and Computer Technology Corporation (MCC), a consortium of companies that concentrates on application-oriented hardware and software R&D in the electronics sector.

MCC's budget totals approximately $55 million per year. It is based in Austin, Texas, and funded almost entirely through private sector funds.[1] MCC conducts advanced R&D in application-oriented computer hardware and software. Chartered largely in response to the Japanese government-sponsored Fifth Generation Computer Project in artificial intelligence, the consortium's R&D program includes projects in artificial intelligence, computer language and architecture, manufacturing and assembly, computer-aided design, superconductivity, and scanning and transfer of leading foreign technologies.[2] Recently, MCC has readjusted its program emphasis to include work in information networks, voice-data integration, and telecommunications.[3]

Since its foundation in 1982, MCC's development has reflected the tension between consortia established to perform long-term research and the desire of member companies for more immediate commercial returns on investment. MCC's charter stressed *long-term* projects in high-risk research, and projects were built around 6 to 10-year time frames. Given this initial focus, some member companies have been concerned over the consortium's apparent difficulty in producing commercializable technology.[4] Technology transfer of the R&D work performed at MCC, moreover, appears to have been hindered by the large proportion of outside personnel directly hired to staff programs.

Recently, MCC has been stressing short-term projects as well as long-term R&D. Incremental improvements in technology and transfer of the initial results of MCC-developed technology to participants have been increasingly emphasized. Operations are being restructured along the lines of a traditional business and have expanded into new areas, including quality assurance, marketing, and time-to-market improvements, considered by many to be as essential to commercial success as possession of leading-edge technology. As in SEMATECH, vertical integration of suppliers and manufacturers has become an important mission.

Government-Industry Collaboration. Examples of past U.S. government support of private sector technology efforts include funding for agricultural extension services, support for basic and applied R&D in computers and semiconductors, support of civilian aircraft and aerospace R&D by the National Advisory Committee for Aeronautics and the National Aeronautics and Space Administration, and R&D energy projects sponsored by the Department of Energy, among others. (See "Government Support Beyond Basic Research" in Chapter 2 for a discussion of these initiatives.)

During the 1980s, Congress enacted several laws aimed at indirect support of private sector technology development and the promotion of government-industry collaboration. The 1980 Stevenson-Wydler Act established information offices on products and services at government-operated laboratories. The 1986 Federal Technology Transfer Act permitted government-owned and government-operated laboratories to conduct cooperative R&D with companies and universities. The 1989 Technology Transfer Act extended the use of cooperative R&D agreements to contractor-operated government facilities.

In addition, the Semiconductor Technology Research Corporation (SEMATECH) was established in 1987 with federal support by the Department of Defense. More recently, the Department of Energy (DOE) has created a program of Cooperative Research and Development Agreements, which it hopes will stimulate technology cooperation between DOE and industry. The Department of Commerce, through the National Institute of Standards and Technology (NIST), operates the Advanced Technology Program which is aimed at promoting cooperative R&D in generic, pre-competitive technologies.

These ventures face several challenges, including determination of the proper allocation of intellectual property rights, division of financial support between public and private sponsors, and effective mechanisms for transferring the results of R&D to member firms, among others.

The founding of the 14-member SEMATECH semiconductor manufacturing consortium marked a significant change in federal policy in civilian technology.[5] It is an example of direct government support for technology development in cooperation with industry in R&D and manufacturing. The Austin-based SEMATECH, which has an annual budget of $225 million, receives $100 million in federal funding support through the Defense Advanced Research Projects Agency, a federal agency. In addition to its headquarters and major research and production facilities in Austin, Texas, SEMATECH established research centers in 11 universities and has joint programs with Oak Ridge and Sandia national laboratories.

It is not possible to provide a definitive assessment of SEMATECH's progress in meeting program or operational objectives.[6] The consortium has only been in operation for four years out of a planned five-year action plan (1988–1993). Several observations, however, can be made regarding SEMATECH's initial programs to assist the competitiveness of the U.S. semiconductor industry.

In addition to supporting semiconductor manufacturers and semiconductor equipment and materials suppliers, SEMATECH should be viewed as an *experiment* in collaboration between industry and the federal government. During its brief history, SEMATECH has pursued a variety of mechanisms to enhance the manufacturing processes, supplier equipment, and business relationships of its member companies and many affiliated firms. The original purpose of SEMATECH was to demonstrate manufacture of dynamic random access memory (DRAM) semiconductors and to support state-of-the-art semiconductor manufacturing technology through demonstration of on-site capabilities in its wafer fabrication plant. The majority of SEMATECH resources was at first targeted for in-house R&D.[7]

SEMATECH officials have concluded that resources should be devoted to areas other on-site manufacturing facilities. The widely varying quality of member companies' production facilities, it is assumed, would limit dissemination of highly sophisticated process technology. In addition, there has been a perceived threat from foreign control over timely supply of finished semiconductors, equipment, and materials to U.S. semiconductor companies. Finally, the change in priorities may have reflected the concerns of SEMATECH's largest participants, whose main concern is on en suring a reliable domestic supply of key semiconductor tools and equipment.[8]

Today, SEMATECH is focusing the majority of its efforts on improving the products of semiconductor equipment suppliers and strengthening the links between semiconductor manufacturers and suppliers of semiconductor manufacturing equipment and materials such as advanced lithography and chemical vapor deposition. SEMATECH is emphasizing direct exchanges of know-how between producers and suppliers[9] and is trying to forge complementary relationships between firms with differing business strengths.[10]

The consortium is also devoting considerable effort to development of equipment standards and methodologies for evaluating semiconductor equipment. Its wafer fabrication plant provides equipment manufacturers with a valuable test bed for new hardware. In addition, the facility is a means for companies, particularly ones without large capital resources, to pool some of their R&D activities.[11] The consortium's most important asset in technology transfer may be its reliance on delegated staff at SEMATECH from member companies. In March 1991, delegated staff constituted about two-thirds of SEMATECH's 335 professional and technical employees.[12] This mechanism heightens the flow of process know-how and research findings to and from the consortium and member companies.

SEMATECH retains a considerable on-site research and development program. For example, it has demonstrated in its laboratory 0.8-micron manufacturing capability with 5-inch wafers.[13] SEMATECH's four major areas of technology development are manufacturing processes, lithography, metallization, and metrology.[14]

NOTES

1. MCC membership includes 21 shareholders and 35 associate firms, as well as government and university participants.
2. MCC's members include Advanced Micro Devices, Andersen Consulting, Bellcore, Boeing, Cadence Design Systems, Control Data Corporation, DEC, Eastman Kodak, Harris, Hewlett-Packard, Honeywell, Hughes Aircraft, Lockheed, Martin Marietta, 3M, Motorola, National Semiconductor, NCR, Northern Telecom, Rockwell International, and Westinghouse Electric.
3. Kirk Ladendorf, "MCC Charting New Course for the '90s," *Austin American-Statesman*, June 9, 1991.
4. Damond Benningfield, "MCC: A Progress Report" (Microelectronic and Computer Technology Corporation, Austin, Tex., May 1988).
5. SEMATECH's members include AMD, AT&T, DEC, Harris, Hewlett-Packard, Intel, IBM, LSI Logic, Micron, Motorola, National Semiconductor, NCR, Rockwell, and Texas Instruments.
6. U.S. Congress, General Accounting Office, *Federal Research: SEMATECH's Efforts to Develop and Transfer Manufacturing Technology* (Washington, D.C.: U.S. Government Printing Office, 1991), 6.

7. Advisory Council on Federal Participation in SEMATECH, *SEMATECH 1990: A Report to Congress* (Washington, D.C., May 1990), ES-4.
8. Ibid., ES-6.
9. Ibid., 23-24.
10. U.S. Congress, Congressional Budget Office, *Using R&D Consortia for Commercial Innovation: SEMATECH, X-Ray Lithography, and High-Resolution Systems* (Washington, D.C.: U.S. Government Printing Office, 1990), 26-31, 34.
11. Ibid., 31, 34.
12. U.S. Congress, General Accounting Office, *Federal Research*, 10.
13. SEMATECH site visit and interviews with SEMATECH staff by John Wilson, January, 1991.
14. SEMATECH has also had some success in constructing the process for characterization and demonstration of equipment and material in 0.5-micron chip production.

APPENDIX F

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