PERSPECTIVES ON U.S. TECHNOLOGY POLICY

Executive Summary

1. Introduction

As American technology policy moves into the 21st century, it evolves within a confident and vigorous new paradigm. Government is seen as a "partner" of industry not an antagonist. "Cooperation" has become the main policy watchword. The health of the "system" of technological innovation offers an overarching policy goal.

Technology policy is an arena of enormous breadth, that demands multiple analytical approaches: history, theory and programmatic evaluation. Though focused on the United States, this book was intended for an audience of non-Americans and non-specialists as well. Its material begins conceptually and historically, exploring the foundations of U.S. technology policy (Chapter 2) A taxonomy of the institutions and actors that define and influence technology policy is then presented (Chapter 3). Chapter 4 focuses on the "mechanisms" of technology policy: funds, rules, programs and policies. Chapter 5 examines ten overriding issues key to the design of technology policy today. Chapter 6 concludes by sketching the trajectory of U.S. technology from its past into the future.

2. Conceptual and Historical Foundations

The Scope of Technology Policy

Technology policy -- the set of laws, incentives and programs intended to encourage and guide the development and use of new technology -- is motivated by diverse goals: national security, economic growth, human health, and environmental protection among them. This report focuses on the subset of policies affecting technology development and use in the civilian commercial sector. Some of these policies are "direct:" providing resources, creating incentives and disincentives, and fixing the "rules of the game" in which technological change occurs. They are carried out through various policy regimes composed of one or more policy "mechanisms" and in the context of particular laws, institutions and programs. Many policies focused on other goals -- market conditions, trade, human resources, etc. -- influence the climate for innovation as importantly, but more "indirectly."

Rationales for Technology Policy

In the United States, rationales for technology policy fall into two broad categories. The first is pragmatic -- actions to encourage, direct, or inhibit technological innovation, diffusion, and use -- using whatever means are available and have the desired impact. The second is philosophical: a set of conditions for "appropriate" action that derive from traditions of limited government, power sharing, and the balance between the market place and societal and communal concerns.

Since the Second World War, and especially during the Cold War, the United States based its national security strategy heavily on the premise that the country could develop and deploy superior military technology. To this end, national security policy emphasized heavy investments in research, development, testing and deployment of the most advanced weapons and communications systems, with little regard to cost. A consensus held that the responsibility for ensuring the availability of such weapons was the Federal government's and that it should do so by mobilizing the technical capabilities of a vibrant private-sector defense industry.

Another consensus rested on the belief that new technology held the means to address disease, aging, and injury. Since the early 1950s the federal government has thus invested heavily in science-based understanding of human maladies, and, in close collaboration, the private sector has produced new preventions and treatments.

United States public policy toward science and technology has differed from that in other countries because, with few exceptions, there is no presumption in the U.S. that the national government should act to address particular national needs. Instead, some rational justification for Federal "intervention" is demanded -- typically, a variant of the theory of "market failure."

If theoretical rigor is the touchstone of what many American analysts and conservatives demand of public policy, history in fact exhibits an additional dynamic: most initiatives in science and technology policy have been responses to real or perceived crises. Just as with war and disease, so too have space exploration, foreign economic competition, environmental degradation and natural resource exhaustion assumed crisis proportions in the "realpolitik" of U.S. technology policy. The result is a technology policy that has been highly cyclic.

If a new, broad, continuous industrial technology policy seems to be emerging in the U.S. today, part of what motivates it is an increased appreciation that new and improved technology offers the foundation for economic growth. Although achieving economic objectives has traditionally been assigned nearly exclusively to the private sector, over the past two decades the view has begun to develop that national investments in education, capital goods and generically applicable new knowledge should supplement private "underinvestment." Beyond this, a new "cooperative" model of the innovation process has taken hold, justifying "partnerships" between the public and private sectors, and casting government as much in a facilitating as in a funding role. This said, a commercial, or "civilian" technology policy remains controversial, and its contours are by no means secure.

3. The Institutional Dynamic

In the U.S., power and influence over an issue as complex as technology policy are divided and shared by many actors. Some hold formal positions of authority in the policy-making process within governments. Others exert influence by virtue of political power, financial resources, or ideas.   No player is dominant. Instead, institutions and organizations vie in a competition of ideas and influence, in which the winning players vary from time to time and issue to issue.

The pluralistic character of U.S. technology policy has its roots in the divided structure of government, specified in the national Constitution. This approach contrasts with many other countries that have a long acceptance of centralization. While the reach of national issues calling for a Federal role has gradually expanded over time, the institutional dynamic in technology policy still reflects the Constitution's philosophy. New Federal policies encounter extended debate; the states play important initiating and implementing roles; and power and influence is balanced among many institutions -- Federal and State, legislative, judicial, and Executive, House and Senate.

The Congress

The Congress plays several distinct roles in the area of technology policy. It passes laws that establish and direct the Federal agencies involved in technology policy, as well as the economic and legal environment in which companies operate. It fixes the budget for the government and provides annual funding for each agency -- a process in which many technology issues are debated and resolved. And it reviews conditions that may suggest new legislation, in which a key element is "oversight" of Executive Branch agencies.

No committee or other body in Congress has responsibility for legislating or appropriating funds across all areas of science and technology, nor does any official body have an overall coordinating role. Instead, science and technology are treated under the committees and subcommittees that have jurisdiction over the departments and agencies where science and technology activities are located.

Unlike in parliamentary governments, the U.S. Congress and its members are independent of the President. The effect is that support for initiatives is never assured. Major legislation is widely discussed, with both lay analysis and expert opinion essential to the outcome.

The Congress has remarkable access to expertise and information. This begins with its large, highly trained staff -- numbering well over 10,000.

It is also served by three analytical and information support groups: the Congressional Research Service (CRS) of the Library of Congress, the Congressional Budget Office (CBO), and the General Accounting Office (GAO). A fourth agency, the Office of Technology Assessment (OTA) was closed in 1995. Congress is adept at getting information from other sources, including Executive agencies, the National Academy of Sciences, and independent experts. Its hearings, especially, serve as a forum where issues are raised and the arguments on all sides of an issue are presented.

The Executive Branch

In the Executive Branch, technology policy activities take place in cabinet Departments, independent agencies, and the Executive Office of the President (EOP). No Department or agency is the dominant actor, a situation made possible both by the relative independence of agencies and their relationships to the Congress and the public.

The major cabinet Departments that support R&D are the Departments of Defense, Energy, Agriculture, Health and Human Services, and Commerce. Important agencies include the National Aeronautics and Space Agency (NASA) and the National Science Foundation (NSF). The EOP has responsibility for coordination and policy direction. Several EOP offices have important roles to play in science and technology policy, including the Office of Science and Technology Policy (OSTP), the Office of Management and Budget (OMB), the National Economic Council (NEC), the National Security Council (NSC), and Council of Economic Advisors.

As in the Congress, much of the policy development in the Executive Branch takes place in the budget process. Budgets in agencies are developed with input from the top down and from the bottom up. Usually the President, working with OMB and OSTP, will set overall targets for each agency and lay out priorities for the coming year. At the same time, people in the R&D agencies, universities, laboratories and industry, routinely offer ideas and budgetary proposals.

The U.S. bureaucracy has more political appointees than is the case in many countries. In consequence, Departments are supportive of Presidential agendas, but politicized; it is relatively easy to change policy, but difficult to engage in long-term planning; agency actions tend to be relatively more consonant with the views of the public, but less guided by technical expertise than in other countries; there is little rivalry between Departments; and career civil service positions are less prestigious than political appointments

The U.S. government has become increasingly process-oriented. While the intent has been to promote fairness or avoid waste, concern arises that this formalization inhibits productivity. In recent years process reforms have been mounted, most recently the "Reinventing Government" effort led by Vice President Gore. In addition, Congress passed the Government Performance and Result Act, which requires the agencies to have strategic plans and to define measurable outcomes.

Advice, Influence and Expertise

The U.S. science and technology policy system relies heavily on a wide network of individuals and groups that provide advice, influence and expertise. Some of its aspects include: formal advisory committees, the National Academy of Sciences complex, think tanks, universities, laboratories, industry groups, issue advocacy organizations, and professional associations. This network -- a powerful but informal science and technology policy community -- connects diverse sources of information with formal decision-makers in government and elsewhere. The value of external advice is widely recognized in complex, technical decisions; in addition, the advisory mechanisms clearly appeal to the American penchant for pluralism and diversity.

The States

The individual states have always played an extremely important role in U.S. technology policy, reaching back to earliest colonial times. During the 19th century, state-Federal partnerships were notable in the system of land grant universities that focused on agriculture and technology. As

Federal funding for science and technology increased dramatically after World War II, the state role shrank. However, by the late 1970s the states had begun to reassert themselves in the development of a new policy model focusing on industrial technology and cooperative ventures that link the public and private sectors.

Although each state is different, their technology initiatives tend to focus on clear and tangible benefits, and they are more pragmatic, less ideological than the Federal government. Despite the continuing Federal debate over "industrial policy", there is widespread consensus that economic development and industrial policy are appropriate activities for state governments. Typical state science and technology programs include: university-industry technology centers, technical assistance, technology financing, start-up assistance, and industrial networks.

4. Mechanisms of Technology Policy

Research and Development Funding

Federal funding of research and development is one of the most important ways the government promotes technology development. Federal R&D has declined, however, as a percentage of gross domestic product (GDP) and relative to industrial R&D. In 1965, Federal R&D was 1.5 % of GDP and nearly double industrial R&D; today industrial R&D is nearly double Federally funded R&D, which has declined to 0.9 % of GDP. The Federal government nevertheless still supports most basic research.

Many Executive Branch agencies contribute to Federal support for R&D: ten agencies fund more than $500 million each in R&D each year. The vast majority of this work is conducted through mission agencies, in which the R&D supports a specific government objective, such as improving defense, energy use, or health. Very little funding supports science and technology for general or economic purposes. Of the approximately $68 billion in Federal R&D, only perhaps $5 billion (in the NSF, parts of the Department of Commerce, and parts of the Department of Energy) is arguably oriented toward general economic objectives.

Mission agency support of R&D, however, has recently shifted toward promoting industrial competitiveness. Over the last decade, many mission agency programs have received more industrial input into program design and more industrial participation in R&D. This shift acknowledges that achieving mission objectives -- e.g., increased energy efficiency or a secure supply of defense-critical electronics -- requires having technology successful in the marketplace.

Federally funded R&D is conducted at universities, Federal laboratories, and in industry. Universities are usually chosen for research that can be conducted by individual investigators or small teams. Federal laboratories are usually used for Federal missions, especially when the large scope of the work or specialized facilities required makes universities inappropriate. Industry is usually chosen for development work, especially when the goal is to have an industrially manufactured product. Over the last two decades, laboratories and universities have developed new formats for interacting with industry so as to make their research more relevant and to accelerate the innovation process.

The process of allocating R&D funds differs by agency and purpose of work. For basic research, agencies often select grantees on the basis of comments from "peer" review panels of scientists active in the field. For mission-related R&D, agency managers typically have a stronger decisionmaking role; however, review panels may still be used for advice.

For basic research grants, projects are evaluated not by the agency, but when research results are submitted to peer-reviewed journals for publication; publication records then influence researchers' chances of getting subsequent grants. R&D programs (aggregated beyond individual projects) are commonly reviewed by external advisory committees at universities, laboratories, and the funding agencies.

Cooperative Mechanisms

"Cooperation" has recently become a watchword of U.S. technology policy. It refers both to a style of conducting R&D -- characterized by exchange of information, networking and collaboration among many researchers -- and to a new pattern of institutional connections -- affiliations among government, industry and academe, as well as internal to each sector. Several factors account for its prevalence: a new paradigm of technological innovation, the view that government and industry should be partners, and political and funding realities.

A broad mandate to support civilian technology was first put into place with the passage of the Stevenson-Wydler Act of 1980. In 1990, the Bush Administration's Technology Policy Statement explicitly endorsed government funding for "generic" technology to contribute to economic welfare. The Clinton Administration later expanded on this concept, through public-private partnerships in pursuit of a wide range of objectives. Although the Republican capture of Congress cast this agenda in doubt, since the elections in 1996, consistent support for a broad innovation and cooperation mandate seems to have reasserted itself.

During the late 1980s, new legislation was enacted to promote technology transfer, changing many features of Federal lab practice, including staffing, patent and licensing law, and financial incentives for technology transfer. The flow of government-supported technology development into private sector commercialization increased significantly during this period.

At the same time, many technical agencies' missions were refocused. Most notable was the creation of the National Institute of Standards and Technology (NIST), with a mission to support industrial technology. The DOD also shifted toward dual-use technology programs, notably through the Technology Reinvestment Project (TRP).

Cooperative R&D Agreements (CRADAs) have become a major policy mechanism, in which labs and industry partners embark on mutually beneficial joint research projects, without any Federal funding of the industrial participants. The legislative framework for this was created in the

1980s, and, after initial difficulties in negotiating legal terms, CRADAs expanded greatly in the early 1990s -- to more than 4000 by 1995. Although the 104th Congress cut CRADA funding, they continue to be major mechanism for industry-laboratory interaction.

Other initiatives set out to remove barriers and create incentives for private firms to cooperate. In 1984, Congress passed the National Cooperative Research Act (NCRA), the first significant amendments to the antitrust laws in a generation. The apparent success of the NCRA in creating private research consortia prompted the National Cooperative Production Act in 1993, which extended antitrust relief to joint production facilities located in the US.

Direct government funding also established cooperative institutions to promote the development and diffusion of industrial technology. Some of the most important cooperative models include:

- The Advanced Technology Program (ATP), begun in 1990 and located within NIST. ATP funds pre-competitive private sector R&D of broad benefit to the nation. About 75% of its funding -- close to $1 billion to date -- has gone to joint ventures, typically involving universities and industry.

- SEMATECH, established in 1987 to combat a declining market share of US chip manufacturers. Originally funded by the Defense Advanced Research Projects Agency (DARPA), SEMATECH is now supported largely by the private sector. The PNGV (Partnership for a New Generation of Vehicles) is also an important sector-specific initiative, directed toward the automobile industry.

- The Manufacturing Extension Partnership (MEP), a network of centers for manufacturing technology diffusion. Cooperatively funded between the states and the Federal government (originally from TRP and the DOC), around 70 such centers now exist. Their principal operating mechanism is extension agents in the field, whose efforts often target small and medium-sized companies.

- Engineering Research Centers (ERCs), university-industry cooperative research centers located at universities. Funded by the NSF beginning in 1984, the ERC program established a prototype for university-industry cooperation and diffusion of academic research to industry during a period of dramatically increased industrial funding of academic research (currently estimated at around $1.5 billion, of which ERCs are only a small part).

Incentives and Rules Affecting the Climate for Technology

A wide variety of legal rules and financial incentives affect the climate for technological change in industry -- both positively and negatively. There has been frequent debate in the U.S. about the extent to which such rules should be tailored to promote innovation. During the 1980, a number of important changes occurred in this direction.

The most visible incentive for innovation in U.S. tax law -- the R&D tax credit -- was enacted in 1981. Modeled to some extent on Japanese tax policy, it rewards incremental increases in corporate R&D. Its impact both on R&D and the budget has been controversial, which has deterred Congress from making it permanent. In 1997 Congress took the long-debated step of decreasing capital gains taxes, a move widely advocated by the technology-based business community.

Though intellectual property rights (IPR) have long been recognized as among the most fundamental incentives for technological innovation, by the early 1980s, some aspects of the laws seemed obsolete. Among various reforms, the most noteworthy is the Bayh-Dole Patent Act, which allowed small businesses and universities to own inventions supported with government funding. Bayh-Dole's approach, regarded as a major boost to commercialization, and has prompted liberalization of IPR policy throughout the government.

Antitrust regulation, an area in which American policy has been uniquely strong, has diverse, often-conflicting impacts on technological innovation. In the early 1980s, the Bell System's break-up ushered in major changes in industry structure and technology. In 1984 and 1993, regulation was loosened so as to facilitate R&D cooperation in industry. More recently, however, traditional antitrust postures -- targeting large, technologically dominant firms -- seem to have reasserted themselves in the challenge to Microsoft brought by both Federal and state governments.

Other Mechanisms

Government procurement has counted historically among the most important influences on technology development in the U.S. DOD's procurement strategy particularly stands out for the breadth of its impact on many different sectors and the degree to which it consciously incorporated incentives for technological innovation.

Although standards development has been a function of the national government since the Constitution, one of the noteworthy features of the US industrial standards process is the degree to which it relies on private bodies as both the initiators and forum through which to achieve consensus. Another important recent development is the rise in international standards, particularly those drafted by the ISO (International Standards Organization).

To a greater extent than in most other countries, U.S. support for the infrastructure underlying technological development has been decentralized -- education, almost wholly a state matter, is perhaps the leading example. Today, one of the hallmarks of the Clinton-Gore technology policy is a renewed emphasis on infrastructure, particularly within the realm of information and communications.

The Small Business Innovation Research (SBIR) program is a unique attempt to change the structure of the overall research enterprise, by setting aside a percentage of Federal R&D grant and contract funds (currently 2.5% for most departments and agencies) for small businesses. Highly popular, SBIR is now the largest civilian technology initiative in monetary terms. In 1992, the STTR program (Technology Transfer) was added. This initiative, recently extended by the Congress until 2001, provides a similar but smaller set-aside to aid in the commercialization of cooperatively developed technologies.

The Federal government's support for information technology provides an example of how support for the development of a technology can occur through a variety of methods. The history of policy in this area extends back to census tabulation in 1890, through the development of the first electronic digital computer in 1945, to the development of the Internet in the 1980s. The Federal government has not only funded information technology R&D, but also has at times been the major purchaser of products using the most advanced technologies. These investments continue today, particularly through the High Performance Computing and Communications Program, spread throughout many agencies and reaching a total funding of more than $1 billion in 1997.

5. Key Issues In Technology Policy

The Appropriate Role of Government

The use of the powers and resources of the federal government to encourage economic development, including making investments in basic infrastructure such as roads, canals, airports, and research and development, has been controversial throughout the nation’s history. With a few exceptions, it was not until the New Deal policies of President Franklin Roosevelt were adopted during the Great Depression of the 1930s that the federal government entered the field of economic development in a major way.

Opponents of federal action have argued for two centuries that economic development is a power reserved to the states, and that the federal government cannot appropriately enter this domain. Proponents have argued that the Constitution does, by implication, give the federal government power to provide incentives to private actors to further its development and expansion.

Political approaches to determining the appropriateness of a federal role in technology and economic development fall into two broad but closely related categories: (1) the exercise of power through government instrumentalities, and

(2) controversies over the government role in which partisan and special interests seek to influence the outcomes of elections and political debates.

Not infrequently, it is argued in the United States that economic theory offers the most legitimate framework to examine and determine the appropriate role for the federal government in technology and economic development policy. From this perspective, economic considerations take precedence over political perspectives -- a view typically adhered to by nearly all mainstream economists, especially those who adopt the neoclassical synthesis. In its "permissive" form, this view is often that of proponents of technology policy. In a "restrictive" form, this is often the perspective of those who oppose a federal role.

In either case, the arguments are rooted in welfare economics, which seeks to maximize the welfare of society by allocating resources to the most productive economic activities. Neoclassical theory finds that the ideal free market is best able to accomplish an efficient allocation. In this framework, an appropriate federal role is an action that most cost-effectively moves society toward the Pareto optimal distribution of resources. However, the ideal free market is a substantial abstraction from the real world. Economists realize that real markets "fail" to achieve the results of ideal markets.

Under the tenets of welfare economics and market failure, government interventions are *appropriate* if and only if they can increase the overall welfare of society. In this framework, it is permissible to use public policy to make some people better off, even at the expense of others, if total welfare increases and so long as it is possible, in theory, for those made better off to compensate those made worse off and still come out ahead. It is important to reiterate that welfare economics takes the existing distribution of wealth and resources in the economy as legitimate. It is not concerned, therefore, with using public policy to address issues associated with inequitable distribution of wealth or other societal inequities.

One way to use the market failure notion is to "permit" or rationalize government intervention -- an approach brought to bear on technology and economic policy analysis in the late 1950s. It was noted that investments in research and development are highly uncertain and that individuals and firms would typically under-invest in such activity compared to a societal optimum. Similarly, it was noted that investments in fundamental research often yield new knowledge whose benefits cannot be captured by the firm that makes the investment. During the 1960s and early 1970s, these concepts became popular among proponents of technology policy because they seemed to offer a principled rationale for government intervention in the market.

With the emergence of a disciplined, conservative and, often, libertarian mode of policy-analytic thought in the United States in the 1970s, the arguments about market failure began to be turned on their head. Thus, the market failure framework was used by opponents of government to restrict it. For them, advocates of an activist government role had failed to measure whether the alleged market failure was large enough to warrant action. More importantly, they observed that advocates had not taken adequate account of the limitations on effective government action; they seek a corresponding acknowledgment of "government failure." The conservative critique also worries that any government intrusion into the marketplace brings costs that are not accounted for by an analysis of any single intervention and that, considering the possibilities of government error, political manipulation of programs, and public venality, it is better not to risk government programs and incentives even if they appear desirable on the surface.

Since market failure analysis can rationalize both restricting and permitting government intervention, it can be argued that this mode of analysis may serve as a totem for deeper beliefs about the efficacy, desirability, and dangers of federal policymaking for the economy.

Given the limits of philosophical approaches to the appropriate federal role, how can governments make pragmatic assessments? One way to determine whether a policy will work is to compare it to policies used in analogous circumstances, in the same country or, perhaps, by comparison with experience abroad: "benchmarking". Other approaches are cost-benefit analysis and program design and evaluation. However one approaches the pragmatic design of policies intended to affect technological changes, the analysis is profoundly dependent on the conceptual model one employs of how technologicial change unfolds. In this regard, there has been substantial movement: from the "linear" model, to the "spin-off," to today's more "systemic" view. From this experience, a set of "guidelines for appropriate policy" can be inferred (see conclusions).

Investing in the Innovation System

Throughout most of the post-World War II period, science and technology policy in the U.S. -- and among OECD members generally -- focused overwhelmingly on support for research and development. Over the last two decades or so, American technology policy has shifted focus, turning the policy paradigm toward investment in the "innovation system."

Policies to support the innovation system have two main foci: 1) the commercial context in which new products, processes and services (innovations) are brought to market, and 2) the interactions among the many influences and actors (the system) that undergird innovation. The implementation of a revised policy context to support the innovation system has rested importantly on acceptance of new scholarship about the nature of innovation in industry. It has also been necessary to broaden the conception of technology policies, to embrace the many components -- as diverse as basic science, venture capital financing, or antitrust regulation -- that are perceived to have an impact on the overall climate for innovation.

The new focus on the innovation system in the U.S. was not created from a central authority, nor quickly. It rests on the gradual accretion of a new conceptual framework, continuing debate, and the vision and commitment of individuals and institutions.

Organization and Coordination

There has been a long-standing debate in the United States about the best way to organize and manage the government's science and technology programs. The issue has primarily been whether Federal support for science and technology should be centralized or decentralized, and, if decentralized, whether the science and technology programs in the various agencies should be strongly or weakly coordinated. Most of the discussion of the issues has pertained to the Executive Branch management of science and technology programs, but similar arguments pertain to Congressional organization. Although these debates resurface from time to time, the U.S. system has maintained its decentralized form in both the Executive Branch and the Congress. What has varied most has been the form and strength of the coordination, primarily in the Executive Branch.

Arguments put forward for consolidation include:

- improved coordination of R&D
- improved setting of priorities
- management consistency
- a Cabinet-level science and technology presence

Arguments against consolidation include:

- R&D separated from agency missions
- reduced diversity in funding R&D
- increased vulnerability to bad administrators or politics
- the need for parallel consolidation in the Congress
- large bureaucracy
- costs and bureaucratic resistance.

There have been two models used to coordinate science and technology programs during the last decade: the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) in the Bush administration, and the National Science and Technology Council (NSTC) during the Clinton administration. NSTC's advantages over FCCSET are that it is chaired by the President, and that the President's Assistant for Science and Technology (the OSTP Director) can exercise authority on behalf of the President and the council through Presidential Decision Directives and Presidential Policy Reviews. An important function of the NSTC is its role in the budget process. The high level of NSTC activity slowed in 1995. In part this was because it was requiring too much time from senior officials, but also because the priorities of the Executive Branch agencies changed in response to changes in the Congress.

Science and technology activities are at least as fragmented in the Congress. Jurisdiction is divided among many House and Senate Committees and 8 different subcommittees of the Appropriations committees. In Congress, each member of Congress essentially represents only a unique constituency, and each acts in his or her own interest. Moreover, there is no coordinating agency in the Congress analogous to OSTP.

Some proposals to reform Congress have suggested reducing the number of committees and appropriations subcommittees with jurisdiction over science and technology. Other proposals would make the committee structures in the House and Senate more parallel. Some proposals argue for more effective coordination across the different committees involved in science and technology in the Congress; however, Congressional committee reform is always difficult. The opportunities for change are greatest when there are major changes in Congress. In 1995 when the Republicans attained the leadership of both the House Senate, there were some changes in Committee jurisdiction, but these did not result in any substantial consolidation of science and technology functions.

University-Industry Relationships

Close relationships between the university and industrial sectors are increasingly seen as essential to the health of a country's overall innovation system. In the U.S., university-industry relationships have evolved dramatically over the last two decades, moving academic institutions far beyond their traditional roles -- education, science, and the performance of publicly funded research -- into cooperation with industry that brings them closer than ever to the commercialization phase of technological innovation. National technology policy has generally urged and supported the emergence a new paradigm in university-industry relations. Within the industrial and university communities, as well, a strong consensus supports the new paradigm, although there is wide recognition of the need to carefully structure the new roles and relationships that are emerging. Some of the reasons for this change include:

- changes in the view of technological innovation, leading to emphasis on cross-sectoral cooperation
- industry's realization of its need for academic expertise
- slowed Federal funding for academic research
- the end of the political estrangement of the university and industry communities
- successful industry-university cooperative ventures
- a wide array of public policies

The American system of university research has a number of key operating features that distinguish it strongly from others. The U.S. has never had a national government agency to establish, fund or direct the agendas of its universities. American faculty members function to a high degree as free agent-entrepreneurs, creating their own funding base and establishing widespread consulting relationships. Personnel mobility is assumed, including recently, growth in the movement of industrial representatives to faculty positions. The sponsored research tradition rests on project rather than institutional funding, with peer review guiding the choice of projects.

Public policies toward the university research system during the 1980s and 90s took a new tack. Funding began to slow, and in many areas dropped significantly. Policy initiatives that emphasized partnerships among the university, industry and governmental sectors arose, including:

- the ERC program of interdisciplinary research centers
- the Bayh-Dole Act
- a basic research tax credit, extended to industry-funded R&D at universities
- university-industry partnering in public R&D projects

The new climate for university-industry cooperative research has created the need for new institutions and practices inside the university community. "Technology licensing offices" are now widespread, cementing university-industry relations and increasing revenues for the university and its faculty through technology commercialization. University-industry research centers now number more than one thousand and are engaged in activities across virtually the entire spectrum of industrially relevant R&D. In 1993, their activities accounted for $2.7 billion, or 63% of the $4.3 billion total industrial funding. Forty-two percent of the centers do chemical and pharmaceutical work, 35 % work on computer-related subjects, 29 % on electronics, 29 % on petroleum, and 26 % on software. The centers expend about 43 % of their effort on basic research, 41 % on applied research, and 16 % on development. Often, such centers also benefit from Federal and state funding.

A new equilibrium seems to have been reached in university-industry research cooperation. It is wiidely seen as among the most effective approaches for managing and addressing a wide range of technology-related issues.

Encouraging New Technology-Based Ventures

In the U.S., new technology-based ventures are seen as the lifeblood of innovation system. They fall into several categories: start-ups, spin-offs, and small businesses. In 1994, about half of all high technology companies in the U.S. were less than 15 years old. In computer and biotechnology-related businesses the proportion was even higher -- about 70 percent. Five high-technology sectors -- software, computer hardware, biotechnology, advanced materials, and telecommunications -- accounted for around 60 percent of new technology-based enterprise formation between 1990 and 1994, a total of 1415 new firms.

New technology-based enterprises depend heavily on "venture capital" financing for innovation, uniquely important in the U.S. Venture capital markets in the U.S. experienced a period of significant growth during the 1990s, and are currently providing close to $10 billion of capital yearly. In the aggregate, venture capital financing in the U.S is more than 10 times as large as similar financing in either Germany or Japan.

New ventures also arise from existing firms: joint R&D, CRADAs, engineering research centers or internal venturing. These have been one of the hallmarks of the last decade, during which, for example, 500 new industrial consortia have been funded and more than 500 companies have joined ERCs.

Another factor creating new ventures in the U.S. is the fluidity of its industrial structure. For example, the number of mergers and acquisitions in the U.S. yearly typically exceeds that in Japan by a factor of 10, and the value difference is even greater.

There has never been a deliberate effort to establish a coordinated set of policies for new ventures. Rather, public policies across the board reflect consciousness of the need to provide a hospitable climate. Some of the many policies in this regard include:

- Venture Capital Companies
- SBICs (Small Business Investment Companies)
- New Business Incubators
- Subchapter S of the tax code, for small business
- Tax loss provisions for investments in new ventures
- ERC's
- Preferences for joint venture under the ATP
- Favorable capital gains taxation for long-term equity investments
- IPR policy -- notably the Bayh-Dole Act
- Project funding
- Technology transfer policies encouraging commercialization
- SBIR and STTR
- Bankruptcy laws

A last -- and perhaps most important -- element necessary to support the development of new technology-based ventures is a social climate that encourages entrepreneurship and risk-taking.

Critical Technologies and Technology Roadmaps

One of the essential questions in technology policy is how to set priorities for investments. This has been less of a problem in science, where the United States has well established mechanisms for setting priorities based on peer review. The situation is different, however, when the government's goal is to encourage a new technology with broad economic benefits.

A first attempt to set priorities, initiated in legislation from the Democratic Congress, was to identify "critical technologies." DOD then created the first critical technologies list. Later OSTP developed a national critical technologies list, and subsequently established the Critical Technologies Institute. During this period (1987-1992) a number of industry organizations identified their own technology priorities, e.g. the private sector Council on Competitiveness. Most of these lists were developed based on the judgment of a group of people with expertise about which technologies were important in some domain.

Technology roadmaps were developed to go beyond critical technology lists and address some of their limitations. The first technology roadmaps to receive national attention were developed by the aerospace and semiconductor industries in the early 1990s. By 1994, several other industries had put together roadmaps, including optoelectronics and electronics packaging.

Although technology roadmaps had antecedents in planning activities in corporations and the DOD, their novelty lay in being done jointly by leading experts in industry, academia, and government. The joint activity was motivated in part by the perception that the U.S. institutions needed to work together to respond to international competitive challenges, and in part by the perception that similar processes to develop visions for industries had worked well in Japan.

Roadmaps can be defined as an "extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field." The typical process is for practicing professionals from industry, academe, and government to convene in a workshop. Roadmaps are often industry-led, but government-facilitated. Participants present views and debate how a particular technology is likely to evolve and what technical developments or new knowledge are needed to for the evolution to occur. Potential roadblocks and alternative ways of achieving the same goal are examined. What typically emerges from this process is a greater degree of consensus among the participants about the timing and technical needs for the development of the technology. The roadmap creates an inventory of technical developments that could contribute to the particular field, and serves to stimulate earlier and more targeted investigations of these technical areas.

Technology roadmaps are beginning to be widely used. In addition to electronics and aerospace industries, the Department of Energy is facilitating roadmaps to guide technologies to improve energy efficiency. Roadmaps have been credited with helping set better priorities and establish new collaborative programs, and it seems likely that they will play an increasing role.

Management of Federal Labs

The United States has approximately 700 Federal Laboratories with annual funding of approximately $24.5 billion. Federal laboratories are GOGOs -- the most numerous -- GOCOs, and FFRDCs (typically university-based centers). The laboratory systems of the Department of Defense (DOD), Department of Energy (DOE), and the National Aeronautics and Space Administration (NASA) account for over 80 percent of the funding for Federal laboratories, and about 20 percent of the Federal R&D budget.

In recent years, Federal laboratories have come under increased scrutiny and criticism. The main concerns have been their missions, their size, their quality and efficiency, and their linkages to industry and universities. Many people have judged the Federal laboratories too large for their missions, too inefficient due to excessive or unnecessary Federal requirements, and too isolated from other parts of the R&D enterprise.

In 1994, President Clinton asked the NSTC to conduct an extensive review of the laboratory systems of the DOD, DOE, and NASA. This resulted in a series of recommendations to review internal management regulations, clarify and focus missions assignments, streamline management, and coordinate and integrate laboratory resources across agencies.

In the early 1990s, with the end of the Cold War and with rising concern about U.S. economic competitiveness, many people thought that Federal labs should shift from their traditional focus to take on a new mission of helping U.S. industry. Although Federal laboratories have attempted to make their work more useful to industry, their fundamental missions have not changed. Among the reasons are continuing defense R&D needs, concerns about labs' abilities, and political resistance.

Concerns about the size of the Federal laboratories are usually expressed not in absolute terms, but rather in terms of Federal laboratories' share of the Federal R&D budget. A number of analyses have recommended moving R&D to universities and away from laboratories.

There are several concerns related to the efficiency and quality of the Federal laboratories. One is that Federal laboratories are relatively isolated from the competitive pressures that have driven efficiency and quality improvement in the private sector and are credited with maintaining quality in universities. Another is that the management structures at the agencies and the laboratories have more layers and more people than they should. This issue takes on different aspects in GOGOs and GOCOs.

Another concern about the Federal laboratories is that their relative isolated from other elements of the nation's R&D enterprise. More and more Federal programs at the laboratories are designed and executed with industry. The interaction with universities is more complex: many labs have long-standing relationships, but for many others more interchange would be desirable. With respect to integration among laboratories, agencies are improving the coordination of internal laboratory systems, due in part to budget pressures, and there is increasing collaboration among agencies, due in part to coordination by NSTC committees. In addition, the Internet and improved computing technologies are facilitating better long-distance collaborations.

Major trends in the Federal laboratory system include a move away from GOGOs, a move toward greater collaboration, and a continued emphasis on improving management practices.

R&D Evaluation

In recent years, increased emphasis has been put on measuring and evaluating the effectiveness of R&D programs. Several factors account for this.

First, budgets have been tight. Second, improvements in government management, in particular, the "Reinventing Government" initiative championed by Vice President Gore, have tried to bring private sector management practices, including performance metrics, into government. Third, the 1993 Government Performance and Results Act (GPRA) imposes specific planning and evaluation requirements on Federal agencies.

R&D evaluation has long been a matter of interest. It is well recognized that R&D evaluation is difficult due to:

- long time periods from the research to outcomes.
- non-linear work flows
- useful contributions of negative results.
- multiple sources of R&D that contribute to outcomes.
- multiple outcomes from single R&D projects.
- subsequent investment needed for desired outcomes

A variety of methods to evaluate R&D have been developed. Quantitative measures of R&D outputs can be used, such as numbers of publication, citations, and patents; the value of patent licensing; awards received; rate-of-return calculations and other economic measures; and many other metrics**.** Qualitative methods include merit review using expert peers, and surveys to measure the satisfaction of the users of the R&D.

GPRA is changing the context in which Federal agencies evaluate R&D. It requires agencies to measure how well programs are making progress towards the intended outcomes and the long-term goals of the agency. Each agency must have a multi-year strategic plan, annual performance plans, and annual program performance reports. The agencies are currently working to comply. They have developed their first round of strategic plans and performance plans, and are required to submit their first performance reports after the end of Fiscal Year 1999. These plans are being reviewed by the Congress and by the General Accounting Office as they are submitted; most submitted to date have received poor grades.

There has been considerable interagency discussion about how R&D programs should best comply with GPRA. Because of the special challenges in assessing fundamental science, the NSTC Committee on Fundamental Science developed a report on assessing science. A government-wide Research Round Table has discussed and supported an approach to evaluation, initially developed by the Army Research Laboratory, that applies to all types of research, from the basic to applied. This approach is to use peer review, quantitative metrics, and customer evaluation to assess the relevance, productivity, and quality of the research.

It is too early to tell what the full effects of GPRA will be on R&D evaluation, and, more importantly, on the performance of R&D in the United States. In summary, GPRA can potentially have a quite positive effect on the management of R&D, but there is also a danger that metrics will be misused and that too great an emphasis on quantitative measures will be counterproductive. The potential strengths and weaknesses of GPRA are amplified by the competition for influence among branches of the U.S. government. It remains to be seen if these forces will cause GPRA to be a positive or negative influence on the management of R&D.

The Role of Defense R&D

For many years, defense research and development played a dominant role in U.S technology policy. U.S. leadership in many areas, including aerospace, electronics, computing and information technology, and advanced materials can be traced to the role of defense R&D.

Defense R&D was effective for three main reasons: 1) its investments were large, 2) it constituted a complete innovation system, and 3) many defense technologies were more advanced than commercial technologies, but similar enough so that commercial technologies could benefit. In recent decades, several aspects of this system changed in ways that have reduced the importance of defense R&D to the civilian economy. First, defense R&D declined substantially as a percentage of the national R&D budget, primarily as private sector R&D grew. Second, in a number of areas, such as electronics and computers, technologies in the commercial sector advanced more rapidly than those in the defense sector. Third, linkages between the commercial and defense sectors of the economy weakened as defense contractors and defense technologies became more specialized.

Today, defense R&D still plays an important, but more limited role. The DOD still funds nearly half of the Federal R&D budget -- $34.9 billion out of $69.4 billion in 1995 -- but of this amount, over $30 billion was for development, not research. DOD is now 6th among Federal agencies in funding basic research, and 2nd (after the NIH) in funding applied research. DOD's impact is still important in selected fields. It is the largest funder of research in mathematics and computer sciences, and is the largest supporter of engineering research. Defense funding has been especially important in areas such as semiconductors, computing, electronics, and network technologies.

DARPA continues to be a driving force in many areas of technology with defense applications. It has made major contributions to information technologies, including reduced instruction set computing (RISC), the Unix operating system, asynchronous transfer mode (ATM) communications protocol, and many others. Companies such as Sun Microsystems, Cisco Systems, and Silicon Graphics have their roots in DARPA-funded R&D. DARPA's current areas of focus are materials science, electronics, tactical technology, information processing technology, and sensors.

International Technical Cooperation

International technical cooperation is an unwieldy arena of policy-making, exacerbated by ambivalence in the way the U.S. views the rest of the world. On the one hand, American society prizes its openness. Access to U.S. science and technology via the university system is entirely open to foreign students and researchers. Foreign investments, whether in R&D or other business activities, are generally welcomed. High-technology industries -- notably the information sector -- depend heavily on foreign workers and actively solicit more.

On the other hand, American policy has been less open in the international domain. Certainly the Cold War period contributed, spawning domestic and international controls on international technology transfer.

Throughout the 1980s and early 1990s, when concern about U.S. competitiveness was highest, the complaint was often heard that there was more to lose than gain economically through international technology cooperation. Even in science, where competitive concerns are muted, politicization has made American support for long-term international projects unpredictable.

Administrative arrangements in the U.S. government illustrate and compound the general problem. Matters of foreign affairs are assigned to the President by the Constitution; nevertheless, the Congress has not been reluctant to assert itself on many issues. Even in the Executive Branch, many agencies are likely to participate in the resolution of any given issue, not always in a coordinated manner. The question of resources -- both financial and personnel -- has also been problematic. For industrial technology projects, particularly, budgets have been very small.

"Big science" and the "IMS" project in manufacturing technology offer two important case studies of the unfolding of U.S. policies toward international technical cooperation.

Foreign access to national technology programs continues to create difficulties for policy-makers and companies. This issue arose during the 1980s, as part of the larger debate about American competitiveness. Particularly in the Congress, the allegation arose that foreign firms -- notably Japanese -- were availing themselves of free access to U.S. science and technology -- notably through university research projects -- to the U.S. competitive detriment. SEMATECH offered one of the first decision-contexts. The approach of a Japanese firm as a potential member met with opposition; however, as the conditions giving rise to SEMATECH have changed over time, the implicit exclusionary policy has been discarded, and SEMATECH's foreign relationships have become common.

For CRADAs, legislation specified a preference for business located in the U.S. that agree that products yielded from research would be manufactured "substantially" in the U.S. The DOE guidelines interpreting this legislation were criticized as too restrictive by firms concerned about the ability to compete globally, leading DOE to take a relatively relaxed stance on foreign eligibility, finding no company ineligible as of 1995. During the decade 1986-97, at least 104 CRADAs were negotiated with foreign companies.

Any company incorporated in the U.S. is eligible to participate in the Advanced Technology Program. Foreign ownership triggers the application of a case-by-case determination in which the company's parent country must provide US firms with reciprocal privileges in public programs, equivalent investment opportunities, and adequate intellectual property protection. As of 1997, there were 21 foreign companies involved in the ATP.

6. Conclusions: The Trajectory of Technology Policy

Technology policy in the U.S. has traditionally been a relatively low-key field, with stable policies and institutions, according to a pattern developed largely in the post-World War II era. The 1980s and 90s saw this established trajectory significantly redirected. Programs to support industrial technology -- the ATP above all -- moved to the forefront of a broad national debate about the appropriate role of government in the economy, whose intense politics are still realigning traditional constituencies. Perhaps more remarkable still was the gradual accretion of a new paradigm of theory, institutional relationships, and funding, which puts cooperation, linkages and partnerships in the forefront of the innovation and public policy agenda.

Why did a new trajectory materialize? Certainly, the competitiveness crisis of the 1980s played a major role. The U.S. began to scrutinize and learn from other countries -- above all, Japan. Scholarship cast new light on technological innovation. The advocacy of visionary individuals must be credited, as well as widespread receptivity to criticism and reform.

Structural Shifts in the Policy Environment

The new paradigm that has emerged in American technology policy has been accompanied by structural shifts in the overall policy environment, which can be expected to continue for the foreseeable future. They include:

- a new balance in R&D funding, in which the majority now derives from private sources; and in which the DOD share has significantly declined
- acceptance of the promotion of technological innovation as a legitimate government mission
- use of cooperative and/or indirect incentives in government technology programs in preference to full direct funding
- cooperative relationships between universities and industry -- often government-supported, as an ever-more-frequent pathway to innovation
- continued emphasis on cooperative technology development in industry

Consensus Politics Reasserted

Although some feared that U.S. science and technology policy was being thrust irrevocably into partisanship after the election of 1994 gave the Republicans control of the Congress, a much more moderate climate now prevails. Philosophically, the proposition that government should support generically applicable technology -- where the private market "underinvests" -- now claims widespread support. Programatically, initiatives like the ATP and MEP enjoy an industrial and academic constituency that supports them not out of ideology, but because they work. If the Congress still seems charged with partisanship, the policy community shares much common ground, and changes in personnel and the political balance of power occasioned by the 1996 election have further muted controversy.

Institutional and Budgetary Stability

The major institutions of U.S. technology policy appear to have entered a period of stability, reflected in a financial picture that is reasonably healthy, and in diminished threats to their mandates. Today, as the Federal budget moves to surplus, a period of level-to-increasing budgets may be foreseen, with some notable increases, such as in the health area. Proposals to reconfigure or eliminate he technical agencies of the government seem a dead issue, with only one organization -- the Congressional Office of Technology Assessment -- a casualty.

Another indicator of stability is the maturation of a number of the Federally supported programs embarked on as experimental: SEMATECH, ERCs and MEP. This evolutionary process rests heavily on the support of a wide range of participating institutions: private firms, universities, and laboratories.

Lastly, fiscal and monetary stability is increasingly recognized as an underpinning for technological change. After years of discussion, the change in tax policy consistently sought by the technology and investment communities -- reduced rates on long-term capital gains -- was enacted in 1997.

Consensus Practice for Appropriate Policies

The changes in the climate for technology policy in the U.S. have yielded a parallel consensus among practitioners in the technology policy community about the way programs should be designed. This consensus may be said to include the following principles of program design:

1. Support the innovation system
2. Recognize that different technologies demand different policy mixes
3. Adopt an experimental, learning approach
4. Encourage firm participation at all stages
5. Use partnership approaches,
6. Stimulate and facilitate the growth of new fields
7. Minimize information needs of program officials
8. Use competitive, merit-based processes

Emerging Technology Policy Issues

As the U.S. technical enterprise moves toward the 21st century, a number of emerging issues loom on the horizon, n one yet fully dealt with, but likely to absorb the policy establishment. Such issues include:

- new technical and policy challenges from the information and service economy
- ways to accommodate the changing fabric of industry structure and competition

- integration between the U.S. and the rest of the world in science and technology
- global environmental problems
- new societal concerns brought about by health questions and genetic technologies