Challenges to technology policy in a changing world

As research and innovation become increasingly global, so, too, must we—in both our mind-sets and our national policies.

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The limitations of the research and innovation policies of the Cold War era are clear, but what will replace those policies? Which relationships will foster science and technology in the new age of distributed and global innovation? What level of investment is required, and how can global investment priorities be determined? What kinds of institutions must be crafted? How will changes be brought into being? The answers to these questions probably will define technology policy into the 21st century.

Americans should not assume that the scientific and technical achievements of the past, which were so effective in winning the Cold War, will be sufficient to sustain future standards of living. "High tech" once described research-intensive industries such as computers, biotechnology, and aircraft. Today, high tech describes a style of work applicable to every business, however uncomplicated its products or services may appear. Skill, imagination, and knowledge—together with new forms of institutional collaboration among firms, universities, and government—can make products and services more effective and productive. Thus, technology policy must be a user-centered and demand-based, not a supply-side, approach.

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If using the full range of available policy tools and working in collaboration with state governments enable the federal government to help firms become more innovative, then the private sector will not only increase its own investment in technology but also demand increased federal investment in research and education. Appreciation for the value of public investments in research then could create the conditions for a business-based political constituency in both parties in support of a farsighted technology policy.

New ways to work

To build a bipartisan consensus for technology policy, both parties must realize that science and technology are deeply intertwined and are often indistinguishable, whereas research and development are quite distinct activities that require different institutional settings and whose sponsors have different expectations. The government's sphere is research, education, and building a knowledge-based infrastructure; industry's sphere is development, production, and the delivery of user benefits. The use of public–private partnerships can join publicly funded research in universities and national laboratories as a powerful institutional mechanism for innovation as long as certain criteria

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are met. These include a sharing of costs in public–private partnerships that reflects the relative expectations for public and private benefits; encouragement of participating firms to share the fruits of the government's investment (but not necessarily of their own), and the government use of rigorously professional and fair merit-based review as the basis for performer selection.

This new way of working with the private sector puts heavy demands on government officials. It was easy to run a technology policy when government decided what kind of research was needed, agreed to pay for it, and picked the people to do it. Now government must work more by indirection and must understand the way the new economy works—sector by sector—much more profoundly. If it succeeds, the public and the business community can build their confidence in a new kind of relationship among government, institutions, and society. Success will be liberating for innovation, as it is for personal freedom.

Roots of political controversy

To understand what kinds of policies might be appropriate in the new world economy and yet politically acceptable in the American system of government, we must review the roots of the political and ideological differences that characterize the debate on research and innovation policy and then search for common ground.

Just when the new American economy is in a position to use much more technical knowledge, the private resources for basic scientific and technological research, formerly done in big corporate laboratories, appear to be shrinking. The new patterns of private-sector innovation depend more on reaching outside the firm to partnerships and alliances, searching out technical knowledge wherever it may be found. These trends appear to call for a government policy that supports alliances among industry, universities, and national laboratories and that uses long-term approaches to compensate for the increasingly short-term investments large firms and their suppliers are making.

Furthermore, large firms seeking collaborative innovation from their supply chains are not confining their searches to local suppliers. If the United States should fade as a leader in technical creativity while Japan, Korea, and China are dramatically accelerating their public investments in scientific and technical infrastructure, then the big companies will simply look elsewhere. For the United States to remain the most attractive location for innovation and advanced research, the basic technological research on which innovation rests must be renewed. Supporters of the Clinton–Gore strategy believe this is a proper—even urgent—role for government (see box, ***The "new" technology policy***).

Former Presidents Ronald Reagan and George Bush did not completely disagree with this role for government. President Bush endorsed federal cost-shared investments in private firms to create "precompetitive, generic" technology in his administration's technology policy declaration of September 1990 (*1*). These two qualifying adjectives, which also appear in the 1988 Omnibus Trade and Competitiveness Act that created the Advanced Technology Program (ATP) in the U.S. Department of Commerce, were intended to ensure that any commercial technology funded by the government was

The "new" technology policy

Taking office with great hopes and a grand vision, the Clinton administration made technology policy a front-burner issue. It unveiled a host of so-called new technology programs as the cornerstone of its investment strategy for the economy, but in fact most of the proposals were extensions or expansions of programs already initiated by Congress and approved by President George Bush.

In a relatively short time, many programs were pushed forward. In the U.S. Department of Commerce, these included the Advanced Technology Program (ATP), to accelerate the development of new technology in the high-technology industry; the Manufacturing Extension Partnership, to help states help small firms use the best production tools and methods; and the Partnership for a New Generation of Vehicles, to accelerate the introduction of new automobiles that consume less fuel. In the Department of Defense, the Technology Reinvestment Project introduced the idea of "dual-use" technology (i.e., applicable to military and civilian uses) and promised to aid in defense conversion. The Environmental Protection Agency established the Environmental Technology Initiative to help industry generate more efficient and less polluting manufacturing processes.

The most controversial of all these new programs was the ATP, which broke new policy ground as the only federal program that provides funds to commercial firms for the sole purpose of accelerating economic progress; the funds are not tied to technology of any special interest to the government.

One of the key elements of the Clinton–Gore approach to technology policy was an attempt to reallocate technology spending from defense to commercial purposes. President Bill Clinton declared his intention to change the civilian-to-military R&D ratio from about 40/60 to 50/50. This change would require an increase of more than $8 billion in civilian R&D—from $27.9 billion in 1993 to $36.6 billion by 1998—and corresponding decreases in defense R&D *(3)*. The FY 1998 budget for outlays, as submitted to Congress, devoted 53.9% to defense and nuclear weapons, representing significant progress toward the 50% goal; however, this progress has been achieved through more defense cuts than civil increases. On the civil side, the growth has been in health research, not in R&D devoted to economic growth.

not yet ready for commercialization and would be of interest to many users (*2*). But President Bush's willingness to accept the Democrats' ATP program at a modest level of funding was not shared by the activists who controlled Congress in 1995. The Clinton–Gore technology program, which had been off to such an auspicious start in 1993, was in trouble two years later.

The political battle over balancing the federal budget provided an opportunity for conservatives in the contentious 1995–96 congressional sessions to raise ideological as well as fiscal objections to the Clinton administration's technology policy priorities and programs. Although one might expect conservatives to support efforts aimed at improving the performance of U.S. companies, many opposed these programs as "corporate welfare". There were calls to abolish the Department of Commerce's Technology Administration (and the department itself), and some members of Congress criticized the administration's high-profile R&D partnerships with the private sector. The vehemence of the attacks came as a surprise to many observers (*4*). The bipartisan policy for U.S. science and technology that appeared to be emerging by the end of the Bush administration collapsed. However, by 1997, the extreme nature of some of the attacks on government funding of technological research seemed to have produced a reaction from moderates in both parties, who appreciated the importance of sorting out the issues and searching for common ground.

New nonpartisan consensus

Early in the 105th Congress, a new flurry of bipartisanship seems to have gripped the President and the Congress. Despite concerns about government distortions of a free market and the necessity to cut the discretionary budget, almost everyone in Congress believes that U.S. ingenuity and research have made the nation strong and prosperous. The Republicans' first-day legislative package for the 1997 congressional session included an unexpected and widely praised authorization bill introduced by Senator Phil Gramm (R-TX) that would double government expenditures in nominal dollars on nondefense basic scientific and medical research over the next 10 years, implying an annual growth rate of some 7% (before inflation). This would be a significant change from the 1996 projections by both the President and Congress, which called for federal nonmilitary R&D to shrink, in constant dollars, by as much as 20–30% in the outer years of their budget-balancing plans.

The line that divides basic scientific research from more immediately useful technological research is unclear.

Leaders in both parties showed evidence of a common interest in resolving science and technology policy issues: A group of highly respected, influential legislators formed a bipartisan Science and Technology Caucus in the Senate, and Chair James Sensenbrenner (R-WI) and ranking minority member George Brown (D-CA) are working well together in the House Science Committee. There is a sense among key legislators that if agreement can be reached on the management of the ATP, then many other program issues will be more easily resolved. The Congress now has a unique opportunity to set a course that could endure for at least a decade and make a huge contribution to American capability and well-being.

Differing views

Given that a willingness to compromise is shared by members of both parties, what are the basic differences between Republican and Democratic views of civilian technology policy? Conservatives have greater confidence in the power of competition to induce firms to invest in technology in pursuit of their commercial interests, which the firms understand in far greater detail than does the government. Most conservatives would agree that market failures may require the government to supplement private investment in special cases. They strongly support federal R&D to develop military and other systems the government wishes to purchase for its own use. But where market failures lead to private underinvestment, conservatives raise warnings about the government's failure to competently remedy a market failure and about the temptation to use public R&D funds for partisan political purposes.

Conservatives and liberals generally agree that government should support basic research in science. They understand that scientific research entails uncertainties about what may be learned, how quickly progress can be made, and how new knowledge might be used in a practical application. The serendipitous discoveries that emerge from science suggest that scientific research is best performed under conditions that allow researchers a lot of freedom. Indeed, scientific research is more about finding good questions than turning out predictable answers.

Bipartisan breakdown

However, the bipartisan agreement that government should support scientific research tends to break down when one moves from the theoretical science disciplines such as astronomy and mathematics to fields seen as more practical, such as chemistry, oceanography, and engineering—in "practical" fields, much more is assumed to be known in advance about how research results might be used.

Politicians are tempted to treat research done in these fields as "applied research", and because the work is assumed to have economic value, conservatives may expect the market to motivate firms to pay for it. Thus, most of the argument centers on the more useful kinds of research, especially when government chooses to fund that research through partnerships with private firms. When commercial firms are invited to share the cost of research with the government, the market failure that justified the public expenditure appears to be modest at best, adding to conservative doubts about its necessity.

The line that divides basic scientific research from more immediately useful technological research is unclear. So, too, is the line that divides technological research from commercial product development. Between science (which has bipartisan support) and commercial product development (which neither party would have government subsidize) lies a large part of the most intellectually exciting and economically useful research. The political controversy about government research subsidies concerns primarily this gray area between "pure" science and development, the area that we call "basic technology research" (*5*).

Challenges facing new policy

We started from the premise that managing a technology policy in support of economic growth is much more complex than implementing the traditional national security-oriented policies of the preceding four decades. This is so, not only because of ideological differences over the appropriateness of government activities in private markets, but also because, for the new policies to be successful, much of the success must come by indirection.

In a defense-oriented R&D economy, the government is the customer for the results of the majority of its R&D investment; however, when government research is to be picked up by private firms and used to compete in world markets, the government is no longer the primary customer. In its economic context, technology always is embedded in a larger business context of production, marketing, and finance.

Technology policy, if it is to contribute to the economy, must be linked to economic policy. For this reason in 1993, the Clinton administration created a National Economic Council, deliberately parallel to the National Security Council, to "monitor the implementation of the new [technology] policies and provide a forum for coordinating technology policy with the policies of the tax, trade, regulatory, economic development, and other economic factors" (*6*).

Technology policy must derive at least part of its legitimacy from the mainstream national concerns about productivity and growth and from the capacity of the private sector to contribute more to public ends such as environmental protection and public health. It should not be seen as simply the "applied" component of science policy. The institutions for policy making in the White House and the Executive Office will have to learn how to marry the function of economic policy making, with its political salience and high stakes, to the traditionally apolitical, low-visibility function of science and technology policy support. (The role of the White House is discussed in Reference 7.)

New approaches to public–private partnerships may be the right strategy for defense and the environment, too.

Reaching bipartisan agreement

Why is it important for Congress and the administration to find common ground for a new policy direction? U.S. firms are competing globally against industrious people in some market economies whose governments are making massive investments in incentives to encourage research and innovation; Americans must agree on how our government should respond.

There are other reasons for rethinking technology policy: New approaches to public–private partnerships may be the right strategy for defense and the environment, too. The new direction for defense acquisition, begun in the last year of President Bush's term, is to seek to use the innovative capacity of commercial firms to a greater extent (*8*). This scheme entails co-investing with private firms in dual-use technology so that the government's investment is leveraged by private funds driving toward similar technological goals. Thus, defense more and more often will ask of industry, "How close can you come to meeting my requirements with your technology and the limited funds we have available?" instead of, "Here are my requirements; what will it cost?" Partnerships become the appropriate institutional relationship, replacing the command economy that characterized a dedicated defense-only industry.

Similarly, the new policy path for dealing with environmental pollution (*9*) will be to supplement end-of-pipe controls with incentives that modify process technologies so that less offensive effluent is produced with little, if any, increase in manufacturing cost. Even the delivery of health care, now being rapidly commercialized in the quest for cost containment, will have its influence on technology policy in the health sector, a trend that has shown up first in the extensive use of Cooperative Research and Development Agreements (CRADAs) by the National Institutes of Health (NIH) and collaborating medical industry firms (*10*).

The government is learning how to leverage research investments and other policies to empower private innovation and to induce behavior in commercial markets so as to reduce the need for federal regulatory intervention (see box, ***Congressional influence on competitiveness***). The administration can claim some success with this kind of enabling policy in its effort to enhance the National Information Infrastructure (*11*). This is the path to achieving public ends at lowest cost, building a strong economic base for the future, and gaining the support of the U.S. public for the long-term commitment to science and technical innovation on which our future depends.

A shifting focus

The search for a bipartisan agreement on the nation's civilian science and technology policies is like chasing a rapidly moving target. The extraordinary changes that are sweeping private industry worldwide call for a new role for government—one that exerts less authority over private activities, listens better to research requirements coming from the private sector, and focuses on enabling innovation and building capacity rather than on creating new things for government use. New patterns of innovative activity and new multifirm industrial structures are emerging. The focus of innovation is shifting from the multinational corporations and their university-like central laboratories to the dozens of hungry firms in their supply chains. This shift in focus is unleashing a wave of opportunity for creativity and entrepreneurship in the smaller firms, but their sights tend to be set on much closer time horizons. While the government has been struggling to find a new set of policy principles for technology appropriate to a shift in priorities from public to private innovation, sweeping changes have been affecting the American economy and its system of innovation.

American corporations have realized that the playing field—for technology development as well as markets—is no longer national; it is global. Firms seek technology sources on a global basis, developing alliances with foreign competitors and establishing laboratories in foreign nations. Foreign companies do the same in the United States. These sweeping changes in the economic environment have made the old technology policies even less effective than they were in the waning years of the Cold War. Thus, the need for a new perspective on government's role arises not only from the transition from military security to economic and domestic security, but also from the need to reflect these sweeping transformations and leverage them to America's advantage.

Congressional influence on competitiveness

The first response of the U.S. Congress to the rising concerns about U.S. high-tech competitiveness was to try to accelerate the spin-off of government technology to the commercial sector. In 1980, the Bayh–Dole Patent Act allowed agencies to grant exclusive licenses for inventions made with their funds. It was followed by the Stevenson–Wydler Act, also in 1980, which encouraged university–industry collaboration. The National Cooperative Research Act of 1984, a response to the view that Japanese consortia of competing firms gave each member firm a competitive advantage, reduced the risk of civil antitrust prosecution of firms collaborating in R&D. The Technology Transfer Act of 1986 (amendments to Stevenson–Wydler) provided a variety of specific incentives for government agencies and national laboratories to enter into Cooperative Research and Development Agreements *(10)*.

In 1988, with President Reagan in the White House and Democrats controlling both congressional houses, Congress passed and the president signed the Omnibus Trade and Competitiveness Act. This statute was the first important institutional change in federal agency structure for addressing the technological dimensions of economic performance. It added new goals and missions to the Department of Commerce's National Bureau of Standards, which changed its name to National Institute for Standards and Technology. A few weeks later, Congress created a Technology Administration in the Department of Commerce with an undersecretary at its head. Subsequently, Presidents Bush and Clinton sought to strengthen the abilities of the Executive Office to coordinate science and technology matters, most recently by the creation of the National Science and Technology Council at the beginning of the Clinton administration.

Although Republicans strongly opposed many of the policy innovations embodied in the Omnibus Trade and Competitiveness Act, they have not repealed any of the legislative authorizations for these institutional changes, even since they won control of the Congress in 1994. Recent fights have been over budgets and appropriations to implement the authorized activities.

Transforming industrial R&D

Responding to changes in the global economic landscape, research-based innovation in the United States and worldwide is undergoing a fundamental shift. The dimensions of this change include

- the increasing pace of technological change;
- the rise of new technology-intensive sectors, such as information technologies, advanced materials, and biotechnology;
- the increasing knowledge intensity of industry;
- the relentless pressure for shorter development cycles;
- the globalization of technology; and
- increasingly complex relationships and interdependencies among corporations, government, and universities.

Underlying and driving these changes is the increasingly distributed and decentralized nature of technology. Industry is shifting from the central R&D laboratory to the international R&D network. In the past, corporations could internalize research and technology development; however, as the sources of technology have become more decentralized and distributed, the challenge has become how to manage external sources of technology. To cope with these changes, corporations are developing new collaborative relationships, alliances, and partnerships; relying more on their suppliers, customers, and users as sources of technology; establishing overseas R&D labs; and forming more partnerships with university and government laboratories (see box, ***Reaching out to universities for technology***, p. 18).

Industrial R&D is extending its focus, monitoring the external environment for potential sources of technology, and seeking to forge the kinds of partnerships required to gain access to those resources. Corporations have increased their reliance on outside suppliers as sources of goods, services, and innovation. In doing so, many companies have reduced, downsized, and in some cases eliminated their central R&D laboratories—once the much-admired centerpieces of the American innovation system (*15*). Some companies have shifted their technology development work to more applied activities; others have increased their reliance on universities for pioneering and applied activities.

New strategies are emerging to meet these challenges. In the past, the large central corporate laboratories of companies such as IBM, AT&T, General Electric, RCA, DuPont, and Xerox were important contributors to the national and international science base. They also were sources of commercial technology and industrial leadership within their own companies. That kind of contribution is now unsustainable. Many corporations have cut back or even eliminated their centralized research laboratories (RCA's Sarnoff Laboratories is the most notable example). Between 1986 and 1993, the average annual growth in industrial R&D was only slightly more than 1%, compared with a 6.7% annual growth rate between 1976 and 1985 (*13*). Tighter R&D budgets are driving industry's quest for more efficient processes, perhaps with a greater realization that no company alone can keep pace with technology and that technology is not the only key to economic success.

To cope with this new environment, corporations are developing strategies that focus R&D resources on core strengths, tie R&D more closely to manufacturing and marketing, and leverage outside sources of technology. Illustrative of this shift are GE's new priorities for its central R&D laboratory:

- educating and training people,
- coordinating work across business units,
- transferring best practices across the company, and
- developing and solving new problems.

Decentralized innovation

Results of a survey conducted by the Industrial Research Institute (IRI) indicated that firms are indeed increasing linkages with the external corporate environment (*16*). IRI found that 49% of the laboratories that responded expect to increase their joint ventures and alliances, whereas only 4% expect to decrease. Additionally, 34% of the R&D labs that responded expect to increase licensing to others, whereas 22% expect to increase licensing from others.

These findings were reinforced by the results of a broad international survey of technology managers that indicated that corporations are relying more heavily than ever on external sources for basic research and product development (*17*). Firms in Europe, North America, and especially Japan see themselves as increasingly dependent on external sources of technology. The study further indicated that corporations use different external sources for basic research and for product development: Universities are the primary external source for basic science, whereas joint ventures and suppliers are the sources of product development. However, even as corporations increase their reliance on external technology sources, internal sources—central R&D labs and divisional R&D units—are still the dominant sources of technology.

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The shift toward distributed technology has been followed by decentralization of technology management responsibilities. The United States has undergone a rapid decentralization of technology since 1994, from the central R&D laboratory to business divisions. Of the U.S. research managers in Roberts' 1994 survey, roughly 60% indicated that they were shifting responsibility for R&D budgets and activities from central laboratories to business units (*17*).

This shift in corporate structures and relationships poses important challenges for American technology policy; it must rely less on the research talents in the largest firms (e.g., IBM, AT&T, and DuPont) and less on the linkage to universities and national laboratories that the corporate

Reaching out to universities for technology

The rise in collaborative R&D efforts among corporations, their suppliers, universities, and even government labs is a clear indicator of the trend toward even more dependence on distributed, external sources of technology. R&D managers throughout the advanced industrial world are decentralizing and globalizing R&D efforts, developing ways to collaborate fruitfully with other companies, suppliers, universities, and government laboratories while focusing their internal efforts on core products and competencies.

IBM, Toshiba, and Siemens, for example, are collaborating on the development of 256-megabit memory chips. Such collaboration extends even to the fiercest direct competitors: Witness the Big Three car manufacturers' United States Council for Automotive Research (USCAR) consortium, supported by the federal government's "Clean Car" effort (a.k.a., Partnership for a New Generation of Vehicles). Collaboration reduces cost, spreads risk, and promotes cross-fertilization of ideas while allowing companies to constantly monitor the external sources of technology. It also places new demands on public support for the research infrastructure that creates new technology opportunities.

The distributed nature of innovation also has brought about countless university–industry research relationships. Universities have become an important component of the R&D system during the past two decades, registering significant gains in the share of research they conduct *(12)*. The university share of total R&D increased between 1970 and 1993 from 8.9 to 12.8%. Universities performed $20.6 billion in R&D in 1993, $10 billion more in real terms than in 1970 *(13)*. Industrial funding of university research also has increased dramatically, another indication of industry's growing reliance on external technology sources. Between 1970 and 1993, industrial funding grew by nearly 600% in real terms from $176 million to $1.2 billion. Industry's share of the total expenditures on academic research grew from 2.6 to 7.3% over the same period *(13)*.

Relationships between university and industry have become more extensive during the past decade or so. Universities sought to cope with federal funding patterns that did not keep pace with demand and responded to changes in federal policy that made federal funding contingent on industry funding. In 1994, there were more than 1000 university–industry research centers (UIRCs) on more than 200 U.S. university campuses *(14)*. These centers spent an estimated $4.1 billion on research and related activities in 1990, $2.5 billion of which was devoted explicitly to R&D. UIRCs give the government a mechanism for accelerating the diffusion of useful technical knowledge to industry while concentrating public resources on advanced research accessible to a broad range of potential users.

The globalization of innovation

The globalization of markets, production, and technology is a defining feature of the new economy. Goods are increasingly produced where they are sold. The sales of goods produced in the global factories of multinational enterprises now total some $6 trillion, an amount that far exceeds the $3.5–4 trillion generated by international trade *(18)*. Exports from foreign subsidiaries of multinational firms now exceed the total exports from the home countries in which those multinationals are based.

A sweeping globalization has taken place in R&D during the past decade, as corporate innovation systems have become international. Today, U.S. multinational enterprises invest nearly $15 billion per year, roughly 10% of their total R&D, in R&D laboratories located in foreign nations *(19, 20)*. Foreign companies account for more than 15% of all R&D conducted in the United States and constitute large and significant shares of the American technology base in fields such as chemicals and pharmaceuticals. In fact, foreign direct investment in R&D comprises the most rapidly growing segment of U.S. R&D.

U.S. corporations are the world's leaders in R&D. According to a 1992 survey of the overseas R&D activities of world's largest 500 corporations, U.S. companies maintained the largest global R&D network, accounting for more than one-third of all overseas laboratories *(21)*. The leading centers for foreign R&D investment by U.S. companies were Germany ($2.5 billion), the United Kingdom ($1.6 billion), and Canada ($1 billion). The notable exception to the pattern of aggressive U.S. foreign investment was in Japan, where government barriers limited investment in R&D by American firms to just $595 million, roughly the same amount that they had invested in Ireland ($573 million) *(19)*.

Japanese companies have expanded their global R&D networks substantially in recent years and currently operate more than 200 R&D laboratories abroad. Japan's international R&D laboratories are concentrated in North America (98) and Asia (81), with a few located in Europe (25) *(22)*.

European companies, which have long operated cross-national networks in Europe, are establishing new laboratories and expanding existing ones in the United States and Japan. For example, Asea Brown Boveri, one of the leading producers of electrical power systems, has organized its extensive network of European laboratories along matrix lines. Under this system R&D projects are coordinated across laboratories in different nations, rather than being undertaken by individual laboratories.

The United States also has become the center for the global R&D explosion. From 1985 to 1995, overseas corporations invested more than $10 billion in 400 R&D centers in the United States. Two-thirds of this spending was concentrated in three sectors: chemicals, drugs, and electronics *(19)*. R&D spending by foreign affiliates grew from $6.5 billion in 1987 to $11.3 billion in 1990, an increase of nearly 75%. Furthermore, the proportion of total U.S. R&D provided by foreign companies grew significantly in the early 1990s. Foreign affiliates devoted roughly 2.5% of sales and 6.5% of value added to R&D, comparable to spending by U.S.-owned firms. The foreign share of total corporate R&D grew from roughly 9% in 1985 to 15.4% in 1990. Foreign R&D accounted for 20% of U.S. high-technology R&D in 1990 *(19)*.

research laboratories have historically provided. It illustrates an important new dimension to technological innovation: Innovation entails organizational change as well as technological advances. Technology policy has long failed to give highly innovative small and medium-sized firms the central role that they deserve. Part of the reason for this failure was that, by necessity, such firms had a short-term perspective on research. But as the center of industrial innovation shifts to these firms and away from fundamental long-term, high-risk research, technology policy must find a way to compensate for this short-term perspective.

Other nations trail the United States in R&D decentralization. Japanese and European corporations continue to move control up the hierarchy from the business unit level, toward more centralized corporate control. Nevertheless, foreign-based firms are increasing their reliance on suppliers as a source of technology and innovation (see box, ***The globalization of innovation***). Japanese companies have long depended on their suppliers as key sources of innovation; German corporations are increasingly using their suppliers as sources of technology.

Globalization challenges some of the most fundamental assumptions of U.S. technology policy.

Many new strategies and structures—variously referred to as "lean production", the "knowledge-based firm", or the "high-performance organization"—are being used worldwide, even though the models differ from one country to the next. This transformation has altered the internal structure of the firm. Now emphasis is on the use of teams, a high degree of task integration, decentralized decision making, continuous innovation, organizational learning, and a blurring of the sites of innovation and production.

Building a national capacity

The globalization of innovation affects the way government intervenes in science and technology policy. Some economists, including Joseph Stiglitz, former chair of the Council of Economic Advisors, have come to believe that science and some aspects of technology are increasingly taking on the characteristics of what they refer to as an "international public good", which tends to flow across national borders and whose shared benefits are enjoyed by all. If true, then this phenomenon raises a series of important questions, especially about the extent to which a national government can offer sufficient incentives for investment in science and technology assets that may later flow beyond its borders.

Globalization challenges some of the most fundamental assumptions of U.S. technology policy. Foremost among these is the notion that technology policy can somehow act on self-contained "national systems of innovation" (*12*). To the extent that all highly industrialized economies are tightly linked through the flow of technology, components, and services, U.S. technology policy must consider the investments of other governments in domestic technological resources and capacity. The policy must shift to systematic concern for the quality of the U.S. workforce, the depth and breadth of new technical knowledge, and the American spirit of entrepreneurship—in short, to the infrastructure for innovation and productivity that will make the United States the most attractive place for innovation. Therefore, although the nation-state may not be the natural unit within which the system of innovation is best understood, the proper concern of public policy is for the national capacity for innovation. The U.S. government can and should contribute to this national capacity.

Capturing benefits for Americans

Unfortunately for the prospects of consensus technology policy, the globalization of R&D and innovation raises very uncomfortable political questions about where U.S. interest lies. Strong voices within both of the dominant political parties are skeptical of the advantages of open markets, lowered barriers to foreign investment, and accelerating diffusion of technical knowledge. They express serious concerns about free riding on U.S.-funded basic and advanced research, exportation of jobs when American firms invest abroad, and foreign control of U.S. R&D assets when foreign firms invest here.

It is true that governments try, usually with limited success, to capture the benefits of their technology investments domestically. They erect barriers to participation in national technology programs by foreign-owned corporations and to the foreign purchase of controlling interests in domestic firms seen as critical assets for national security.

For more information

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In October 1996, the Clinton administration invited the authors of the 18 chapters to examine and evaluate the success of new policies that had been implemented by President Bill Clinton and Vice President Al Gore. In the book, an expansion of a summary report of findings published in April 1997, the authors use a new set of technology policy principles to evaluate many federal research programs and make recommendations for change. They offer guidelines for stimulating technological innovation, shaping public and private partnerships, and establishing criteria for federal investment in research.

To order the book directly from the publisher, call 800-356-0343, send an e-mail to **mitpress-orders@mit.edu**, or visit The MIT Press online at **http://mitpress.mit.edu**.

However, we believe that government's attempts to manipulate the flow of benefits from public investments in R&D against the tide of global markets is fruitless and potentially destructive. Once innovations have been internalized in a firm, the firm must be free to deploy those assets the best way it can—which could mean selling the assets to a buyer at some time. To do otherwise abrogates to government the very market power to which those who believe in private enterprise most object.

Current policy seeks a reasonable and moderated response to these political concerns. Foreign-owned firms are allowed to participate in most government programs if their own governments accord similar benefits to U.S. subsidiaries in their home countries. Barriers to foreign direct investment have been raised only in rare cases.

The U.S. government is trying to find ways to enhance the respect for U.S. intellectual property abroad and to express concern about importation of goods produced by child or prison labor or without concern for environmental consequences. As the world economy becomes more open, with the entry of former Communist states into world markets, and with the growth of third-world production, these political concerns are expected to rise.

It will take new international understanding and perhaps institutional innovation to resist political pressure to stem the tide of globalization. A positive, investment-based strategy is the best antidote to projectionist pressures. The federal government should help U.S. firms respond to the competitive challenge of a fast-changing global marketplace. Government should be able to do it without meddling in domestic markets or favoring competitors. This investment strategy may find support on both sides of the political aisle, because it is constrained more by budget deficits than by economic ideology.

The new role for government

Economists are revising their view on the appropriate nature and role of government involvement in science and technology. In the late 1950s and early 1960s, Nelson (*23*) and Arrow (*24*) provided compelling economic logic for greater government support of R&D. They argued that R&D offered tremendous potential social returns, but it often was just too risky for private firms to make the required investments. Government support was required to close the gap and to ensure that sufficient levels and kinds of R&D investment were undertaken.

Recent economic research on the process of technological innovation and on the government's role in support of science and technology notes the importance of "spillovers" of two kinds: knowledge and consumer surplus. Knowledge spillovers derive from the public-good nature of knowledge, combined with the difficulty of keeping economically useful knowledge secret when it is profitably exploited. Such spillovers can be derived from reverse engineering, when some aspects of a competitor's technology may be discovered by examining how the competitive product is made. Even negative information—the abandonment of a line of work by a respected competitor, for example—can be a useful spillover.

Consumer surplus spillovers result from the creation of new goods or the improvement of existing ones. The innovator captures only part of the consumer value in the sales price; there may be a social surplus that exceeds the innovator's profit.

Research tends to generate more knowledge spillovers, which is a reason for government support, but research alone cannot generate consumer surplus spillovers. These come from product and process development.

Private firms have inadequate incentives (to varying degrees, depending on market structure and other considerations) to take new ideas to market. Furthermore, the transfer of potentially useful ideas from the government or university sector to the private sector does not happen automatically or without cost. For better or worse, if government or university scientists are not given incentives to transfer their commercially useful ideas to the for-profit sector, many ideas will languish.

Complementarities

Economists who study innovation also note that there are complementarities among research, development, and human capital. One major reason that firms do research is to develop the internal capability to absorb and use others' research (*25*). The ability of a firm to appropriate knowledge spillovers to its advantage is limited by its absorptive capacity. Thus, from a public policy perspective, nations whose firms do very little research may find it difficult to appropriate the "international public goods" represented by U.S. research investments. To maximize the social return on public research investments, preference should be given to intrinsically promising research in which the spillovers to the intended beneficiaries—primarily U.S. firms—are greatest.

Patel and Pavitt have called attention to the importance of the institutional efficiency and creativity with which an economy responds to competitive pressures and opportunities (*26*). The prevailing economic theory of the 1960s, they argue, predicted that buoyant demand and an open trading system would allow the international (and domestic) diffusion of technology and, in turn, would lead to equalization of technological performance at the national level. They claim that this prediction was based on a flawed model of science-based development and technological change. The model assumed that

- "embodied" technical change would derive from investment in better machinery—imported machines incorporate process technology within their designs, available to all who purchase them;
- "unembodied" change would arise from the relatively costless diffusion of knowledge that is codified as "information" in books, journals, drawings, and patents; and
- unembodied change also would be acquired as "tacit" knowledge, resulting from relatively costless "learning by doing".

> **Government must develop clear and measurable goals for innovation-based economic progress.**

If this model were equally applicable to all countries in a similar state of development, it would follow that through markets for machinery, free access to codified technical knowledge, and a rapid process of learning by doing, the gaps between the economies of the United States, Japan, the United Kingdom, Germany, and France should have closed during their recovery from World War II; they did not. Japan and Germany have moved ahead, but the United Kingdom and France have fallen behind. In three decades, Taiwan, Korea, and Singapore have leapt ahead technologically from a very backward state, while Brazil, Mexico, and India have failed to do so (although they show signs of progress).

All three assumptions are elements of the technology diffusion process, but the efficiency of these processes varies strongly from one institutional setting to another. Patel and Pavitt concluded that technology diffusion, productivity learning, and transfer of embodied technology are vulnerable to cultural, managerial, and institutional barriers (*26*). Thus, they focused attention on the importance of investments in education, training, R&D, and efficient inter-institutional collaboration. These also are the attributes of a society described by Fountain (*27*).

Government efforts—which helped to create the broad institutional contours of the post-World War II R&D system—now must be strategically recast to inform the new institutional relationships among industry, university, and government required for a new system of research-based innovation to emerge and prosper. The role of the extensive network of government laboratories, which consumes more than $25 billion in federal R&D spending per year, must be reexamined in terms of changing economic and technological realities. The federal government must develop clear and measurable goals for innovation-based economic progress so that the private sector can gauge the effectiveness of new institutions, policies, and programs. Federal science and technology initiatives must be aligned with broader economic, trade, and regulatory policy initiatives and goals. All of this must be consistent within its global context.

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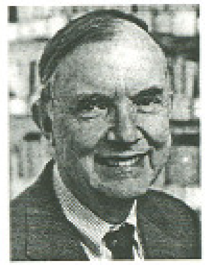

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"We don't know the answer yet, but we're really getting off on the attention."