..ing in Innovation

Creating a Research and Innovation Policy That Works

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Challenges to Technology Policy in a Changing World Economy

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"The economy, stupid," James Carville wrote on a white board in the campaign headquarters of candidate Bill Clinton during his run for the White House in 1992.[1] Shortly after taking office, President Clinton and Vice President Gore issued a major report on technology policy, "Technology for America's Economic Growth: A New Direction to Build Economic Strength." Reflecting themes outlined in an earlier campaign statement, the president outlined a new direction and role for the federal government to build economic strength and spur economic growth:

> American technology must move in a new direction.... We cannot rely on the serendipitous application of defense technology to the private sector. We must aim directly at these new challenges and focus our efforts on the new opportunities before us, recognizing that government can play a key role helping private firms develop and profit from innovations.[2]

To what degree has the Clinton administration delivered on these promises? Is it even appropriate for the federal government to help "private firms develop and profit from innovations?" Do the 1993 policy directions adequately reflect the changes sweeping over private industry in an increasingly global economy? What are the most appropriate and effective lines of action for both the administration and the Congress to build a more effective technology policy for the future? What lessons should be taken from the experience of the last four years?

This book takes up these questions. It reflects the analyses and assessments of a broadly based group of experts who have examined the successes and disappointments of the administration's implementation of its first term technology policy. The experts do not always agree, except on one point: there is no single right answer—no "one size fits all" technology policy that would best serve the nation.

The chapters provide assessments of key Clinton administration programs and initiatives. The book also offers suggestions for policy directions that take advantage of what has been learned. The aim of this book is to define a set of policies, and principles to guide them, that are both timely for action now and also might endure over the time scales necessary for research and innovation incentives to bear economic fruit.

In addition, this book seeks to shed light on some of the broader, more conceptual issues surrounding government intervention in science and technology. What should be the guideposts for federal scientific and technological intervention in the nation's economic life? What should be done at the federal level, and what should and can be done by the states? What are the most appropriate and effective policy tools and mechanisms? What is the proper mix of policy tools?

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 (but in many cases repackaged) technology programs as the cornerstone of its investment strategy for the economy.[3] In a relatively short time (certainly short for action in Washington, D.C.) a torrent of programs was pushed forward. In the Commerce Department, these included the Advanced Technology Program (ATP) to accelerate development of new technology in high-tech industry; the Manufacturing Extension Partnership, helping states assist small firms to use the best production tools and methods; and the Partnership for a New Generation of Vehicles (PNGV) to accelerate the introduction of new, less fuel-consuming power plants in automobiles. In the Defense Department, the Technology Reinvestment Project (TRP)[4] introduced the idea of dual-use (civilian and military) technology and promised to aid in defense conversion. The Environmental Protection Agency (EPA) initiated the Environmental Technology Initiative (ETI) to help industry generate more efficient and less

polluting manufacturing processes. The most controversial of these programs has been ATP, which broke new policy ground as the only federal program providing funds to commercial firms for the sole purpose of accelerating economic progress, not tied to any specific technology of 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. The president declared his intention to rebalance the ratio of civilian to military R&D from about 40:60 to 50:50. This would require an increase of over $8 billion in civilian R&D, from $27.9 billion in 1993 to $36.6 billion by 1998, while defense R&D expenditures declined.[5]

Even more dramatic, those programs specifically devoted to private sector incentives for research-based innovation—such as the ATP, the TRP, and the multi-agency Small Business Innovation and Research (SBIR) program—were so small compared to defense spending that extraordinary growth rates would be necessary to bring R&D spending aimed at economic progress to a level equal to that for defense. The political problems this effort might entail were understood to be significant, but few anticipated the backlash from conservatives that came with the election of a Republican majority to the 104th Congress in 1994.

Ideological objections to what conservatives call "industrial policy" and "corporate welfare" removed any doubts that the 104th Congress would reject a rapid shift in R&D spending from military to the administration's civil technology initiatives. Social liberals also opposed "corporate welfare" as a diversion of resources from traditional welfare; indeed they had invented the phrase, only to see it co-oped by conservatives as a signal of opposition to government expenditures seen as wasteful. The boldness of the Clinton-Gore plan and the budget priority assigned to it may have had the effect of politicizing technology policy. From the conservative perspective, the administration's desire for rapid increases in these programs stood in the way of tax reductions and budget balancing. More importantly, there were some basic issues related to the nature and scope of government interventions in technology that were of great concern to many in Congress.

Nonetheless, the 105th Congress, elected in the fall of 1996, seems much more willing to search for common ground on many of these issues. An opportunity to build a new consensus based on sound principles that meet the legitimate concerns of both the administration and the Congress seemed to be at hand in the spring of 1997.

The commitment of both political parties to a balanced federal budget requires that government extract the maximum value from every dollar invested in the research and development of technology. These new fiscal realities are also shaping a rethinking of how government can most effectively support innovation, both in the private sector and in its own operations. Such a rethinking creates the opportunity to develop new models and strategies for technology policy which can overcome existing ideological and partisan differences. A bipartisan strategy is essential to the long-term stability needed to foster technology and the economic benefits that flow from technological leadership.

Looking Forward

The limitations of the research and innovation policies of the Cold War period are clear, but what will replace them? What 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 these changes be brought into being? These are the questions that are likely to define technology policy into the twenty-first century, and they are the subjects of this book.

Americans should not assume that the scientific and technical achievements of the past, so effective in winning the Cold War, will be sufficient to sustain rising living standards in the future. "High-tech" was once a description of research-intensive industries such as computers, biotechnology, and aircraft. Today, high-tech is a style of work applicable to every business, however simple its products or services may appear. Skill, imagination, and knowledge, together with new forms of institutional collaboration between firms, universities, and government, can make products and

services more effective and productive. Thus, technology policy must be user-centered and demand-based, in contrast to a supply-side approach.

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

Building a bipartisan consensus for technology policy requires a recognition that science and technology are deeply intertwined and often indistinguishable, in contrast to research and development, which are quite distinct activities calling for different institutional settings and different expectations from their sponsors. The government's sphere is research, along with education, and the building of a knowledge-based infrastructure; industry's sphere is development, along with production, and delivery of user benefits. If the sharing of costs in public-private partnerships reflects the relative expectations for public and private benefits; if the participating firms are encouraged to share the fruits of the government's investment (but not necessarily of their own); if the government uses rigorously professional and fair merit-based review as the basis for performer selection, then the use of public-private partnerships can join publicly funded research in universities and national laboratories as a powerful institutional mechanism for innovation.

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 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 between government and the institutions and people in our society. This will be liberating for innovation, just as it is liberating for personal freedom.

This first chapter explores the roots of the political conflict over technology policy, and traces the evolution of both the debate and the policies that emerged from it. The political pressure for policy change flowed from perceived weaknesses in the U.S. economy—lagging personal incomes, layoffs in high-wage employment, and sales of U.S. industrial assets to foreign investors—as American firms faced increasing competition from abroad in the 1970s and 1980s. The chapter then explores the changes that firms have made in the way they innovate and how they relate to sources of technology outside the firm, as they have restored their manufacturing competitiveness. These changes, especially the move toward less hierarchical and more collaborative relationships among firms, their suppliers, and sources of technical knowledge and skill, call for additional changes in the way government tries to help empower innovation in the economy. We then discuss the importance to firms of sources of technical knowledge for which government has a special responsibility, including university ties to industrial firms, which government has encouraged. Finally we address the implications for policy of the rapid globalization of innovation activities. The chapter closes with a brief synopsis of each of the chapters of the book.

The Roots of Political Controversy over Technology Policy

To understand what kinds of policies might be both appropriate in the new world economy and also politically acceptable within the American system of government, we must begin by reviewing the roots of the political and ideological differences that characterize the debate, and then search for common ground.

Just at the time when the new American economy is in a position to use much more technical knowledge, the sources of private support for the basic scientific and technological research formerly carried out 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 government policy that supports alliances among firms, universities, and national laboratories, and that compensates with long-term approaches 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 search for innovation to local suppliers. If the United States should fade as a leader in technical creativity, just at the time Japan, Korea, and China are dramatically accelerating their public investments in scientific and technical infrastructure, the big companies will simply look to foreign sources for those innovative suppliers. For the United States to remain the most attractive location for innovation and advanced research requires renewal of the basic technological research on which innovation rests. Those who support the Clinton-Gore strategy believe this is a proper, even urgent, role for government.

Presidents Reagan and Bush did not totally disagree with this. 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.[6] These two qualifying adjectives, which appear in the 1988 Omnibus Trade and Competitiveness Act creating the Advanced Technology Program (ATP) in the Department of Commerce, were intended to make sure that any commercial technology funded by government was precompetitive (not yet ready for commercialization) and was generic (of interest to many users).[7] 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 the Congress in 1995. The Clinton-Gore technology program, 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 for the abolition of the Commerce Department's Technology Administration (and the Department itself), and some criticized the administration's high-profile R&D partnerships with the prigovernment, 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 quite 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 subsidies to research concerns primarily this gray area between "pure" science and development, in the area we call "basic technology research" (see Chapter 5).

Challenges Facing a New Research and Innovation Policy

This book starts 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 because, for the new policies to be successful, much of the success must come by indirection. In a defense-oriented R&D economy, government is the customer for the fruits of most of its R&D investment, but when government research is to be picked up by private firms and used to compete in world markets, government is no longer the primary customer. In its economic context, technology is always embedded in a larger business context of production, marketing, and finance. Technology policy, if it is to contribute to the economy, must in turn be linked to economic policy. It was for this reason that the administration in 1993 created, in deliberate parallel to the National Security Council, a National Economic Council (NEC) 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."[9]

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, public health, and the like. 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 White House role is discussed in Chapter 17 by David Hart.)

The Importance of Reaching Bipartisan Agreement

Why is it important for the Congress and the administration to try to find common ground for a new policy direction? U.S. firms are competing globally against industrious people in market economies whose governments are making massive investments in research and innovation incentives; 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 environment too. The new direction for defense acquisition, already begun in the last year of President Bush's term, is to seek to utilize the innovative capacity of commercial firms to a greater extent (as Linda Cohen explains in Chapter 7). This entails co-investing with private firms in "dual-use" technology (applicable to both military and civil uses) so that the government's investment is leveraged by private funds driving towards similar technological goals. Thus defense will, more and more often, ask of industry, "how close can you come to meeting my requirements with your technology and the limited funds we have available?" instead of saying, "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 (as discussed in Chapter 11 by George Heaton and Darryl Banks) will be to supplement end-of-pipe controls with incentives to modify process technologies so that less offensive effluent is produced without adding much, if any, cost to the product being made. 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 (discussed in Chapter 9 by David Guston).

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. The administration can claim some success with this kind of enabling policy in its effort to enhance the National Information Infrastructure (see Chapter 13 by Brian Kahin). This is the path to achieving public ends at lowest cost, to building a strong economic base for the future, and for gaining the support of the U.S. public for the long term commitment to science and technical innovation on which our future depends.

The Evolution of U.S. Technology Policy after World War II

To understand the opportunities and constraints on policy for the future, it is important to see the current scene in historical context. During the first four decades after World War II, the United States attained the highest level of scientific and technological achievement in history.[10] With the world's largest economy and the strongest armed forces, it helped to defend the cause of free societies and demonstrated the strength of market economies. There was little foreign competition for the new defense-based high-tech U.S. industries. The nation met the security threat from the Soviet Union with massive commitments to technological superiority. When, in 1957, the Soviet Sputnik rattled public confidence in this strategy the nation put on a spectacular demonstration of its capability to mobilize and deploy technology, by going to the moon. The period from the early 1950s to about 1968, after which the growth of government investments in R&D came to a halt for ten years, is often called the golden age of American science and technology.[11]

Despite the success of these policies in containing Soviet expansionism and demonstrating technical prowess, there were early indications, as Japan and Germany recovered from the war, that the defense-based science and technology policies might not be sufficient to assure a strong economy. In 1968, Michael Boretzky, a Commerce Department economic analyst, began to document for a succession of Commerce secretaries and for the intelligence committees of the Congress the erosion, already visible by 1968, of the previous highly favorable balance of trade in high technology goods.[12] President Nixon entertained a presentation from his special trade representative, Peter G. Peterson, documenting the situation. Nixon's Secretary of Commerce Maurice Stans made a strong appeal to Congress for investment in research to reverse this high-tech trend.[13] President Carter, during his last year in office, chartered a major study of how the federal government might enhance innovation rates in the private sector. The study, completed for the secretary of commerce by Assistant Secretary for Science and Technology Jordan Baruch, was presented to Congress, but with the election of President Reagan it lost any opportunity to influence policy.[14]

It was President Reagan who introduced concern about competitiveness into the political discourse by declaring an administration "competitiveness" strategy.[15] But high-tech erosion continued, and in 1986 the U.S. high-tech trade balance went negative for the first time. Thus the government's concern with ensuring a competitive commercial economy against technologically sophisticated competition from abroad began to provoke policy responses long before the fall of the Berlin Wall in 1989.

In the first two decades after World War II, both mission-based technology and general scientific research were supported by the mission agencies, primarily the Department of Defense. Budgets of the National Science Foundation (NSF) and the National Institutes of Health were relatively modest. As a guarantee against central political control over scientific and engineering activities, American policy after the war called for a highly decentralized responsibility for investing in research and development by federal agencies. All federal agencies were to develop the technology needed for their assigned tasks and were also to support a proportionate share of the country's basic research, as a kind of "mission overhead" reinvestment in the basic knowledge on which their technology depended.[16] The autonomy of academic science was to be preserved by competitive selection, through peer review of proposals.

The two main elements of postwar technology policy, then, were government support for research in basic science, and active development of advanced technology by federal agencies in pursuit of their statutory missions.[17] The assumption that these activities would sustain a competitive private economy was derived from a supply-side picture of how the process of innovation works in high-technology industries. This postwar technology policy approach, followed by France and Britain as well as the United States, has been characterized by Henry Ergas as mission-oriented technology policy, in contrast to the diffusion-oriented policies of Germany, Switzerland, and Sweden.[18]

The bipartisan support for science in the postwar period rested on two assumptions. The first was acceptance of the "pipeline model" of the process by which social return arises from scientific research in the form of industrial innovations. Innovations, in this model, arise from scientific research and invention, followed sequentially by product development and production. While this is not a bad description of how new industries arise from new science—a process that usually takes a decade or more—it is inapplicable to the way existing industries compete through rapid incremental progress in which product and process development, driven by market opportunity, provide the stimulus to research.[19] The pipeline model is an even less appropriate description of how high-technology firms compete in the 1990s.

The second assumption was that technology created in pursuit of governmental missions, especially defense, space, and nuclear energy, would automatically flow to industry and make for prosperity. The process through which this is presumed to happen is called "spinoff."[20] A key reason for its appeal is that spinoff, like the pipeline from basic science to innovation, is assumed to be automatic and cost-free. Both of these assumptions have the attractive feature that if these processes are automatic and cost-free, the government does not have to "pick winners and losers" in order for the economy to gain the benefits. Government can then claim that its policies achieve the goals of economic growth without interference with the autonomy of private firms. This argument still constitutes the core of the conservative opposition to active governmental interest in the diffusion and commercialization of government research, and even stronger objections to government R&D investments to meet commercial requirements for new technology.

In short, U.S. policy after the Second World War, with its pipeline and spinoff images, sought to avoid the business community's abhorrence of industrial policy and the scientists' abhorrence of centrally planned science, while still retaining the benefits of technological stimulation of the economy. The political attractiveness of this policy helps explain its persistence, despite the fact that its assumptions are no longer realistic today. But the alarms first sounded by Michael Boretsky in the late 1960s suggested that there were flaws in the assumption that the pipeline from science and the spinoff from technology to commercial markets was either automatic or free.

The first response of Congress to the rising concerns about U.S. high-tech competitiveness was to try to accelerate the spinoff of government technology to the commercial sector, beginning with the Bayh-Dole Patent Act in 1980, which allowed agencies to grant exclusive licenses for inventions made with the agency's funds. It was followed by the Stevenson-Wydler Act of 1980, encouraging university-industry collaboration. The National Cooperative Research Act of 1984 reduced the risk of civil anti-trust prosecution of firms collaborating in R&D, a response to the view that Japanese consortia of competing firms gave them a competitive advantage. 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 (CRADAs, discussed in Chapter 9 by David Guston).

In 1988, with President Reagan in the White House but with Democrats in control of both the House of Representatives and the Senate, the Congress passed and the president signed the Omnibus Trade and Competitiveness Act. This statute, in which Senator Hollings of South Carolina played an important role, represented 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 Commerce

Department's National Bureau of Standards (NBS) and changed its name to National Institute for Standards and Technology (NIST). A few weeks later, Congress created a Technology Administration (TA) in the Department of Commerce with an undersecretary at its head. Subsequently both President Bush and President Clinton sought to strengthen the capabilities of the Executive Office to coordinate science and technology matters, most recently by the creation of the National Science and Technology Council (NSTC). Despite strong Republican opposition to many of the policy innovations embodied in the Omnibus Trade and Competitiveness Act, even after they won control of the Congress in 1994, none of the legislative authorizations for these institutional changes has been repealed. The recent fight has been over budgets and appropriations to implement the authorized activities.

Until 1988, it was reasonable to suppose that the Department of Defense (DoD) would continue to focus its main effort on neutralizing the strategic threat from the Soviet Union, even as it began to rely more on dual-use technologies as a means of shortening defense systems development cycles, reducing acquisition costs, and indirectly making a contribution to the defense industrial base. The Department of Energy (DOE) still placed top priority on its nuclear weapons program, even as it began to broaden its technical activities into the Human Genome project and high-performance computing in support of new opportunities for the computer industry.

The Commerce Department, until the 1988 law, had been the main focus of debates about federal roles in support of industrial competitiveness, but there had been little change in its agency structure or functions. Indeed, the Reagan administration attempted to disestablish much of the activity in fire research, building technology, and computer engineering at the National Bureau of Standards. These were among the NBS activities directed most specifically at assistance to industry. Only a sympathetic Congressional ear to objections from industry trade associations kept these activities in place.

During the 1980s, the National Science Foundation (NSF) had begun to build up its investment in fundamental engineering

research in the universities. It initiated two new programs (the Engineering Research Centers and the Science and Technology Centers) intended to promote interdisciplinary research in universities in which industry participation would be required. Further evidence of interest in associating NSF with industrial interests was a brief (and abortive) effort by Congress to restructure the Commerce Department by merging the National Bureau of Standards with the National Science Foundation, and to redefine the mission of the Department as a "Department of Trade and Industry."[21]

The assumption that government R&D in pursuit of agency missions such as defense was what commercial firms needed to remain competitive could no longer be sustained when the Berlin Wall fell in 1989. U.S. self-interest then shifted rapidly from a first priority on Cold War security to a first priority on economic performance and domestic issues. Studies of competitiveness issues showed that where foreign industries seemed to have better performance, it was not in R&D but in downstream functions of quality and cost of manufacturing and in the quick pace of product cycles.[22] Congress, with Senator Jeff Bingaman from New Mexico in the lead, began to shift its focus from research and development to technology, asking the administration for a series of studies of critical technologies and establishing the Critical Technologies Institute (CTI) as a Federally Funded Research and Development Center (FFRDC) supporting the Office of Science and Technology Policy (OSTP).[23] At this point, major changes in U.S. policy began to appear, as outlined in Table 1-1.

The break with reliance on the spinoff model was now clear, and was reflected, or at least implied, in the Clinton-Gore technology policy announced on February 22, 1993. The pace and scale of these proposals and the administration's implicit confidence in their efficacy marked a dramatic change from the policy proposals of the 1970s and 1980s. Central was a proposed shift in the balance between military and civil R&D expenditures requiring spectacular growth in the civil R&D programs. The political difficulties associated with executing this plan were clearly identified at the time.[24] The resulting intense and often emotional debate between the Republican-controlled Congress and the administration has displayed radically different views about how the U.S. government

Table 1-1 Changes in the Policy Environment for Government Technology Programs

New program environment	Cold War era environment
Consensus management by cooperative agreement	Federal financing and control by contract
Technology adoption by internalization of R&D	Technology transfer to industry assumed or required
Expanded scope; goal is industry transformation	Single goal defined by engineering objective
Complementary assets are important to success	Principal risks are technical or market uncertainty
Recursive innovation model	Pipeline innovation model
Technologies for design, process, and quality are important	Emphasis placed on precompetitive research, plus development for government uses
Difficult to create constituency for program	Danger of constituency capture of program
Firms are selected by competitive negotiation on likelihood of commercialization	Firms are selected by contract competition on fulfillment of government specifications

should deal with the competitive challenge to U.S. industry that emerged in the 1980s.

It is a thesis of this book that many of these political difficulties could be resolved with careful attention to what is known and indisputable about the role of government activities in the innovation process and the language used to discuss it. However, while the effort to resolve these ideological differences proceeds—and it is making progress in the 105th Congress—the world economy is hurtling into new territory. Any forward-looking technology policy must deal with the world of innovation as it will be in the next decade, not as it was in the last.

A Moving Target for Policy: New Patterns of Innovation and Research

The search for a bi-partisan agreement on the nation's civilian science and technology policies is chasing a rapidly moving target.

The extraordinary changes that are sweeping over private industry all around the world 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 more on enabling innovation and building capacity than on creating new things for government use. New patterns of innovative activity and new multi-firm industrial structures are emerging. The focus of innovation is shifting from the multinationals and their university-like central laboratories to the dozens of hungry firms in their supply chains. This 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. At the same time that 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 both the economy and the American system of innovation.

American corporations have come to realize—now more than ever—that the playing field is on longer national but global. That goes not only for markets, but for technology development as well. Firms are seeking out sources of technology on a global basis, developing alliances with foreign competitors, and establishing laboratories in foreign nations. Foreign companies are doing the same in the United States. These sweeping changes in the economic environment have made the old technology policies even less effective than they already were in the waning years of 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 from the need to reflect these sweeping transformations and leverage them to American advantage.

Transformation of Industrial R&D

Responding to these and other changes in the global economic landscape, research-based innovation in the United States and around the world is undergoing a fundamental shift. The dimensions are 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 cycle times; the globalization of technology; and increasingly complex relationships and interdependencies between corporations, government, and university.

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 global R&D network. In the past, corporations could internalize research and technology development, but 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 upon their suppliers, customers, and users as sources of technology; establishing overseas R&D labs; and increasing their partnerships with universities and government laboratories.

Industrial R&D is extending its focus, monitoring the external environment for potential sources of technology, and seeking to forge the partnerships required to gain access to them. Corporations have increased their reliance on outside suppliers both as sources of goods and service and as sources of innovation. In doing so, many companies have reduced, downsized, and in some cases eliminated their central R&D laboratories, once the much-admired centerpiece of the American innovation system.[25] Some have shifted their technology development work to more applied activities, while others have increased their reliance on universities for both pioneering and applied activities.

New strategies are emerging to meet these challenges. In the past, the large central corporate laboratories of companies like IBM, AT&T, General Electric, RCA, DuPont, and Xerox served as important contributors to the national and international science base, as well as being sources of commercial technology and industrial leadership within their own companies. That is now unsustainable. A number of corporations have cut back, and in some cases eliminated, their centralized research laboratories, RCA's Sarnoff Laboratories being the most notable example. Between 1986 and 1993, the average annual growth in industrial R&D was just slightly

better than 1 percent, compared to a 6.7 percent annual growth rate between 1976 and 1985.[26] Tighter research and development budgets are driving industry's quest for more efficient R&D, perhaps with a greater realization that no company can keep pace with technology by itself, and that technology is not the only key to economic success.

To cope with this new environment, corporations are developing new strategies which 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, which include educating and training people, coordinating work across business units, transferring best practices across the company, and only last, developing and solving new problems.

Reaching out to Universities for Technology

The rise in collaborative research and development efforts among corporations, their suppliers, universities, and even government labs is a clear indicator of the trend toward ever more dependence on distributed, external sources of technology. R&D managers across the advanced industrial world are decentralizing and globalizing R&D efforts, developing ways to collaborate fruitfully with other companies, suppliers, universities, and government labs while focusing their internal efforts on core products and competencies. For example, IBM, Toshiba, and Siemens are collaborating on the development of 256-megabit memory chips. Such collaboration is even extending to the fiercest direct competitors: witness the Big Three car manufacturers' joint USCAR consortium, supported by the federal government's "Clean Car" (PNGV) effort. Collaboration reduces cost, spreads risk, and promotes cross-fertilization of ideas, while allowing companies to monitor constantly the external sources of technology. It also places new demands on public support for the research infrastructure that creates new technological opportunities.

The distributed nature of innovation has also resulted in an explosion in university-industry research relationships. Universities have become an important component of the R&D system over the past two decades, registering significant gains in the share of research they conduct (see Chapter 14 by Harvey Brooks and Lucien Randazzese). The university share of total research and development increased between 1970 and 1993 from 8.9 percent to 12.8 percent. Universities performed $20.6 billion in R&D in 1993, $10 billion more in real terms than in 1970.[27] Industrial funding of university research has also increased dramatically in recent years, providing a further indication of industry's growing reliance on external sources of technology. It grew by nearly 600 percent in real terms between 1970 and 1993, from $176 million to $1.2 billion. Industry's share of the total expenditures on academic research grew from 2.6 to 7.3 percent over the same period.[28]

Relationships between university and industry have grown more extensive over the past decade or so, as universities have sought to cope with federal funding patterns that have not kept pace with demand, and have responded to changes in federal policy that made federal funding contingent on industry funding. The explosion of university-industry research relationships has been even larger than anticipated. There are now more than 1,000 university-industry research centers (UIRCs) on more than 200 U.S. university campuses.[29] They spent an estimated $4.1 billion on research and related activities in 1990, $2.5 billion of which was devoted explicitly to research and development. University-industry centers provide government with 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.

Decentralized Innovation

A recent survey by the Industrial Research Institute indicates that firms are indeed increasing linkages with the external corporate environment.[30] According to the IRI study, 49 percent of laboratories expect to increase their joint ventures and alliances, while just four percent expect this to decrease. Additionally, 34 percent of R&D labs expect to increase licensing to others, while 22 percent expect to increase licensing from others. These findings are reinforced by a broad international survey of technology managers in

North America, Europe, and Japan, which indicate that corporations are relying more heavily than ever on external sources for both basic research and product development.[31] Firms in Europe, North America, and especially Japan see themselves as increasingly dependent on external sources of technology. The study further indicates that corporations utilize different external sources for basic research and for product development. Universities are the primary external source for basic science, while, for product development, corporations rely much more on joint ventures and suppliers. Even as corporations increase their reliance on external sources of technology, however, internal sources—both central R&D labs and divisional R&D units—are still the dominant sources of technology.

The shift toward distributed technology has been followed by decentralization of technology management responsibilities. The United States has undergone a rapid decentralization of technology over the past three years, from the central R&D laboratory to business divisions. Roughly 60 percent of the U.S. research managers in the survey indicated that they were shifting responsibility for R&D budgets and activities from central laboratories to business units.[32] This shift in corporate structures and relationships poses important challenges for American technology policy. It must begin to rely less on the research talents in the largest firms, such as IBM, AT&T, and Dupont, and less on the linkage to universities and national laboratories which the corporate research laboratories provided historically. This illustrates an important new dimension to technological innovation: innovation entails organizational change as well as advances in technology. Second, 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 reluctance was the fact that, by necessity, small and medium 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 the decentralization of R&D. 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 also increasing their reliance on suppliers as a source of technology and innovation. Japanese companies have long depended upon their suppliers as a key source of innovation. German corporations are increasing their use of suppliers as a source of technology. The trend to new strategies and structures referred to variously as "lean production," the "knowledge-based firm," or the "high-performance organization" is worldwide, even though the models differ from one country to the next. This transformation has altered the internal structure of the firm, with new emphasis 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.

The Globalization of Innovation

Globalization of markets, production, and technology is another 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 totals some $6 trillion, an amount which far exceeds the $3.5 to $4 trillion generated by international trade.[33] The exports from foreign subsidiaries of multinational firms now exceed the total exports from the home countries in which those multinationals are based.

The past decade has seen the sweeping globalization of R&D, as corporate innovation systems have become international in scope. Today, U.S. multinational enterprises invest nearly $15 billion per year, roughly 10 percent of their total R&D spending, in R&D laboratories located in foreign nations.[34] Foreign companies account for more than 15 percent of all R&D conducted in the United States, and constitute large and significant shares of the American technology base in fields like chemicals and pharmaceuticals. In fact, foreign direct investment (FDI) in R&D by foreign enterprises comprises the most rapidly growing segment of U.S. R&D.

U.S. corporations are the world's leaders in global R&D. According to a recent 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 a third of all overseas laboratories.[35] The leading centers for foreign R&D investment by U.S. companies are 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 is Japan, where government barriers limited investment in R&D by American firms to just $595 million, roughly the same amount as they invested in Ireland ($573 million).[36]

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 smaller number (25) located in Europe.[37] 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, a leading producer of electrical power systems, Asea Brown Boveri, has organized its extensive network of European laboratories along matrix lines, under which R&D projects are coordinated across laboratories in different nations, rather than being undertaken by individual laboratories.

The United States has also become the center for the global R&D explosion. Over the past decade, overseas corporations have invested more than $10 billion in 400 research and development centers in the United States. Two thirds of this spending is concentrated in three sectors: chemicals, drugs, and electronics.[38] R&D spending by foreign affiliates grew from $6.5 billion in 1987 to $11.3 billion in 1990, an increase of nearly 75 percent. Furthermore, the proportion of total U.S. R&D provided by foreign companies has grown significantly over the past few years. Foreign affiliates devote roughly 2.5 percent of sales to R&D, and 6.5 percent of value-added, comparable to spending by U.S. owned firms. The foreign share of total corporate R&D grew from roughly 9 percent in 1985 to 15.4 percent in 1990. Foreign R&D accounted for one out of every five dollars of U.S. high-technology R&D in 1990.[39]

Building a National Capacity for Innovation

These changes affect the way government intervenes in the areas of science and technology policy. Some economists, including former

Chairman of the Council of Economic Advisors Joseph Stiglitz, 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," a good that tends to flow across national borders and whose shared benefits are enjoyed by all. If true, this 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 then flow away beyond its borders.

Globalization challenges some of most fundamental assumptions of U.S. technology policy. Foremost among these is the notion that technology policy can somehow act upon self-contained "national systems of innovation."[40] To the extent that all highly industrialized economies are tightly linked through the flow of technology, components, and services, U.S. technology policy must take into account 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, the American spirit of entrepreneurship—in short, to the infrastructure for innovation and productivity that will make America the most attractive place for innovation. Thus, while 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. How the U.S. government can and should contribute to this national capacity is the primary focus of this book.

Capturing Benefits of Technology Policy for Americans

Unfortunately for the prospects of consensus technology policy, the globalization of R&D and of innovation raises very uncomfortable political questions about where the 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. Concerns are expressed about free-riding on U.S.-funded basic and advanced research, about the exportation of jobs when American firms invest abroad, about 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 barriers to foreign purchases of controlling interests in domestic firms seen as critical assets for national security.

However, we believe that attempts by government to manipulate the flow of benefits from public investments in R&D against the tide of global markets is both fruitless and potentially destructive. Once the innovations have been internalized in a firm, it must be free to deploy these assets in the best way it can, including the possibility that it might sell the assets to a foreign owner at some time in the future. To do otherwise abrogates to government the very market power to which those who believe in private enterprise most object. As a result, 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 country. Barriers to foreign direct investment have been raised only in rare cases. The American 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 produced under conditions of severe environmental degradation. As the world economy becomes more open, and with the entry of former communist states into world markets and the growth of third world production, these political concerns may be expected to rise.

It will take new international understandings and perhaps institutional innovations to resist political pressures to attempt to stem the tide of globalization. A positive, investment-based strategy is the best antidote to projectionist pressures. Government should try to help U.S. firms respond to the competitive challenge of a fast-changing global marketplace and should be able to do it without meddling in domestic markets or favoring selected competitors. There does seem to be reason to believe that this investment strategy may find support on both sides of the political aisle, constrained as it is more by budget deficits than by economic ideology.

The New Role for Government in Research and Innovation

In recent years, economists have begun to revise their view on the appropriate nature and role of government involvement in science and technology. Writing in the late 1950s and early 1960s, Kenneth Arrow and Richard Nelson provided a compelling economic logic for greater government support of R&D.[41] R&D offered tremendous potential social returns, they argued, but it was often 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 types 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 note the importance of so-called "spillovers" of two kinds.[42] 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 his product is made. Even negative information, the abandonment of a line of work by a respected competitor, for example, can be a useful spillover of his decision.

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, by itself, 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 costlessly or automatically. For better or worse, if government or university scientists are not given any incentive to transfer their commercially useful ideas to the for-profit sector, many of these ideas will languish.

Economists who study innovation also note that there are complementarities among research, development, and human

capital. A major reason firms do research is to develop the internal capability to absorb and utilize others' research.[43] 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 research where the spillovers to the intended beneficiaries—primarily U.S. firms—are greatest, providing the research is intrinsically promising.

Pavitt and Patel have also called attention to the importance of the institutional efficiency and creativity with which an economy responds to competitive pressures and opportunities. The economic theory prevailing in the 1960s, they argue, predicted that buoyant demand and an open trading system would allow the international (and domestic) diffusion of technology and this would lead to equalization of technological performance at the national level.[44] Pavitt and Patel argue that this prediction was based on a flawed model of science-based development and of technological change. It supposed that: a) "embodied" technical change would derive from investment in better machinery: imported machines incorporate process technology within their designs, available to all who purchase; b) "unembodied" change would arise from the relatively costless diffusion of knowledge that is codified as "information" in books, journals, drawings, patents, etc.; c) unembodied change also is assumed to be acquired as "tacit" knowledge, resulting from relatively costless "learning by doing."

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 U.S. economy, and those of Japan, the U.K., Germany, and France should have closed during their recovery from World War II. It did not happen. Japan and Germany have moved ahead, while the U.K. and France have fallen behind. In three decades Taiwan, Korea, Singapore have leapt ahead from a very backward state, while Brazil, Mexico, and India have failed to do so (although they show signs of progress).

All three of those assumptions are elements of the technology diffusion process, but the efficiency of each of these processes appears to vary strongly from one institutional setting to another. Patel and Pavitt conclude that technology diffusion, productivity learning, and transfer of embodied technology are vulnerable to cultural, managerial, and institutional barriers. Thus they focused attention on the importance of investments in education, training, R&D, and efficient inter-institutional collaboration. These are the attributes of a society that Jane Fountain describes as social capital in Chapter 4.

Government efforts—which helped to create the broad institutional contours of the postwar R&D system—must now be strategically recast to inform the new institutional relationships between industry, government, and university required for a new system of research-based innovation to emerge, prosper, and flourish. 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 light 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 initiative and goals. All of this must be consistent within its global context.

Outline of the Book

This book is presented in three parts. The first part explores the changing environment for technology policy. It tackles the big picture, providing insights on the key questions of technology and economic growth, the role of social capital in facilitating innovation, and appropriate measures of technology policy effectiveness. It also outlines appropriate areas for direct federal investment in scientific and technological research. Chapter 2 by Michael Borrus and Jay Stowsky shows how technology policy contributes to economic and productivity growth. In Chapter 3, Adam Jaffe discusses how to measure the effectiveness of technology policy. He concludes from his review of the models of analysis underlying current legislation that new and more effective measures are badly needed. He also advances the notion of using experimental designs to test the efficacy of technology policy interventions. Chapter 4 by Jane Fountain explores the role of social capital in innovation and technology policy. Social capital describes the capacity of individuals and economic institutions to innovate with high levels of productivity. Key attributes of social capital include "trust, norms, and networks that can improve the efficiency of society by facilitating coordinated actions."[45] The last chapter in this first part, written by Lewis Branscomb, explores the nature of scientific and technological research and the opportunities it presents for federal investment. Branscomb argues that technological research often includes work that is fundamental and precompetitive in the same way that basic scientific research can be, and that what the nation needs is not a "technology policy" to go with its science policy, but a more broadly defined "research policy" that provides knowledge and skills to support a policy for promoting innovation.

The second part of the book assesses seven specific technology programs promoted by the Clinton-Gore administration. In Chapter 6, Christopher Hill reviews the history and current controversies surrounding the Advanced Technology Program (ATP) in the National Institute for Standards and Technology. Hill describes the need and justification for this program, and recommends a series of steps that would strengthen and expand it. Linda Cohen, in Chapter 7, examines the Technology Reinvestment Project (TRP) and its successor, the Dual-Use Applications Program (DUAP), which embodies the Defense Department's new approach to acquiring technology for military use through collaboration with commercial firms in research leading to dual-use applications, those with both commercial and government markets. Cohen identifies a number of institutional factors in the defense department and in industry that have presented barriers to the TRP program goals and concludes with recommendations on other means of achieving TRP dual-use objectives.

In Chapter 8, Scott Wallsten reviews the role of the federal government's Small Business Innovation Research Program (SBIR), which supports commercial R&D among small firms through an obligatory set-aside of agency R&D appropriations. His review of

Harvey Brooks, *Technology and Global Industry: Companies and Nations in the World Economy* (Washington, D.C.: National Academy Press, 1987), p. 192.

19. Ralph Gomory, "From the 'Ladder of Science' to the Product Development Cycle," *Harvard Business Review*, November–December 1989, pp. 99–105.

20. Alic, Branscomb, Brooks, Carter, and Epstein, *Beyond Spinoff.*

21. This somewhat curious proposal was intended to strengthen the Commerce Department's role in competitiveness by gathering together under its roof most of the elements of trade policy, but it would have removed from the department its capability to understand industrial technology. It would thus have been a pale copy of Japan's Ministry of International Trade and Industry (MITI) despite the fact that the proposed name, DITI, seemed intended to call MITI to mind.

22. Michael L. Dertouzos, Richard K. Lester, and Robert M. Solow, *Made in America: Regaining the Productive Edge* (Cambridge, Mass.: The MIT Press, 1989).

23. Lewis M. Branscomb, "Targeting Critical Technologies." in Branscomb, ed., *Empowering Technology*, chap. 2, pp. 36–63.

24. Branscomb "Empowering Technology Policy," chap. 9 in *Empowering Technology*, pp. 266–294.

25. Richard Nelson, ed., *National Innovation Systems: a Comparative Analysis* (New York: Oxford University Press, 1993).

26. National Science Board, *Science and Engineering Indicators 1993* (Washington, D.C.: National Science Foundation, 1994).

27. Ibid.

28. Ibid.

29. Wesley Cohen, Richard Florida, and W. Richard Goe, "University-Industry Research Centers in the United States," Carnegie Mellon University, Pittsburgh, July 1994. An initial survey was sent to all 437 universities and colleges that were recipients of industry-sponsored research between 1981 and 1988; it identified 1,056 university-industry research centers. A second, more detailed survey was sent to all 1,056 university-industry research centers, generating 511 responses, for an adjusted response rate of 48.4 percent.

30. The Industrial Research Institute (IRI) sent questionnaires to the official representatives of 253 IRI members in the United States. The survey generated responses from 158 companies for a response rate of 62 percent.

31. Edward Roberts surveyed 244 global firms that perform approximately 80 percent of worldwide R&D. Completed surveys were provided by 95 firms, of which 46 were from the United States, 27 were from Europe, and 22 were from Japan. The response from German firms was low; the remaining Western European companies, however, had an overall response rate of 51 percent. Edward Roberts, "Strategic Benchmarking of Technology," Sloan School of Management, MIT, Cambridge, Mass., 1994.

32. Ibid.

33. United Nations Division on Transnational Corporations and Investment, *World Investment Report 1995, Transnational Corporations and Competitiveness* (New York: United Nations, 1995.

34. Donald Dalton and Manuel Serapio, *Globalizing Industrial Research and Development* (Washington, D.C.: U.S. Department of Commerce, Office of Technology Policy, 1995). Also see Richard Florida, "The Globalization of R&D: Foreign-Affiliated Laboratories in the U.S.," *Research Policy*, Vol. 26 (1997), pp. 85–103.

35. Robert D. Pearce and Satwinder Singh, *Globalizing Research and Development* (New York: St. Martin's Press, 1992).

36. Dalton and Serapio, *Globalizing Industrial Research and Development.*

37. MITI, *Fourth Annual Survey on Japanese Overseas Activities* (Tokyo: MITI, 1994).

38. In 1990, foreign R&D affiliates accounted for 58.9 percent of industrial chemical R&D, 42 percent of pharmaceutical R&D, and 7–10 percent of the R&D in consumer electronics, in computers and office equipment, and in electronic components. Dalton and Serapio, *Globalizing Industrial Research and Development.*

39. Ibid.

40. Nelson, *National Innovation Systems.*

41. Kenneth J. Arrow, "Economic welfare and the allocation of resources for invention," in *The Rate and Direction of Inventive Activity: Economic and Social Factors, A Report of the National Bureau of Economic Research* (Princeton, N.J.: Princeton University Press, 1962). Richard R. Nelson, "The simple economics of basic research," *Journal of Political Economy*, Vol. 67 (1959), pp. 297–306.

42. We are indebted to Adam Jaffe of Brandeis University for his contributions to this discussion of spillovers.

43. Wesley M. Cohen, and Daniel A. Levinthal, "Innovation and Learning: The Two faces of R&D," *The Economic Journal*, Vol. 99, No. 397, 1989, pp. 569–596.

44. Pari Patel and Keith Pavitt, "The Nature and Economic Importance of National Innovation Systems," *STI Review*, No. 14 (1994), pp. 9–32.

45. Robert Putnam, *Making Democracy Work: Civic Traditions in Modern Italy* (Princeton, N.J.: Princeton University Press, 1993), p. 167.

46. *The State-Federal Technology Policy Task Force—Final Report*, September 5, 1995.