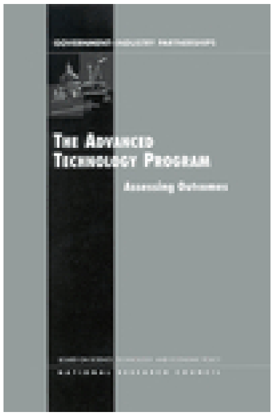

The Advanced Technology Program: Assessing Outcomes

Charles W. Wessner, Editor, Board on Science, Technology, and Economic Policy, National Research Council

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For the National Research Council (NRC), this project was overseen by the Board on Science, Technology and Economic Policy (STEP), a standing board of the NRC established by the National Academies of Sciences and Engineering and the Institute of Medicine in 1991. The mandate of the STEP Board is to integrate understanding of scientific, technological, and economic elements in the formulation of national policies to promote the economic well-being of the United States. A distinctive characteristic of STEP's approach is its frequent interactions with public and private-sector decision makers. STEP bridges the disciplines of business management, engineering, economics, and the social sciences to bring diverse expertise to bear on pressing public policy questions. The members of the STEP Board* and the NRC staff are listed below:

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Foreword

The National Institute of Standards and Technology (NIST) asked the National Research Council's (NRC) Board on Science, Technology, and Economic Policy (STEP) to review the operations of the Advanced Technology Program (ATP) to ascertain if the program is achieving its legislated objectives and to recommend potential improvements in its operations.[1]

The ATP is a program administered by the Department of Commerce's National Institute of Standards and Technology to provide cost-shared funding to industry to accelerate the development and broad dissemination of challenging, high-risk technologies that promise broad-based economic benefits for the nation.[2] The program seeks to support

- emerging and enabling technologies facing technical challenges, which, if overcome, would contribute to the future development of new and substantially improved products, industrial processes, and services in diverse areas of application;

[1] In Senate Report 105-235, the Advanced Technology Program was directed to arrange for a well-regarded organization with significant business and economic experience to conduct a comprehensive assessment of the ATP, analyzing how well the program has performed against the goals established in its authorizing statute, the Omnibus Trade and Competitiveness Act of 1988. In January 1999 NIST requested that the Board on Science, Technology, and Economic Policy conduct this assessment as part of its broader review of *Government-Industry Partnerships for the Development of New Technologies* (described in the Preface).

[2] The ATP was established in 1990 under the Omnibus Trade and Competitiveness Act of 1988 (P. L. 100-418), as amended by the American Technology Preeminence Act of 1991 (P. L. 102-245).

- technologies whose development often involves complex "systems" problems requiring a collaborative effort by multiple organizations;
- technologies that, because of their risk, or because firms are unable to fully capture their benefits, are unlikely to be developed by individual firms, or may proceed too slowly to compete in rapidly changing world markets without the impetus of an ATP award.[3]

The ATP provides a leading role for industry, balanced by government and outside expert review. Companies conceive, propose, co-fund, and execute all of the projects. The ATP role is to identify the most promising projects that require outside support and contribute to their development on a cost-shared basis.

This review of the ATP is being conducted under the auspices of the STEP Board's broader study of *Government-Industry Partnerships for the Development of New Technologies,* a study designed to review and address the policy issues associated with public-private collaboration to bring new technologies to the market. It is widely recognized that new technologies make an important contribution to economic growth while enhancing the capacity of the government to perform major national missions in areas such as defense, the environment, and health.

The NRC analysis in this report constitutes the second phase of the review carried out under the *Government-Industry Partnerships* study. The first phase report summarized a workshop designed to lay out the goals of the ATP, its method of operation and evolution, the views of the program's critics, and the experiences of its users, that is, the winners of its competitive awards. This second report includes five chapters in addition to the Executive Summary which follows. Chapter I, the Preface, provides background information and describes the *Partnerships* project and the goals of this study. Chapter II, the Introduction, places the ATP in the context of U.S. technology policy and summarizes the symposium and the commissioned papers. Chapter III provides the Committee's findings and recommendations concerning the performance and operation of the program. Chapter IV provides a detailed summary of the proceedings from the most recent National Research Council conference on the Advanced Technology Program, which includes the perspective of administrators, company participants, and analysts of the program. Chapter V includes six independent analyses illustrative of the ATP assessment program as well as a description of the current selection process by NIST officials.

[3] The ATP funds technical research but not product development.

Executive Summary

BACKGROUND

In response to a Senate mandate, the National Institute of Standards and Technology (NIST) asked the National Research Council (NRC) to review the performance of the Advanced Technology Program (ATP) in light of its legislated goals and to make recommendations for improvements, where appropriate, in the operations of the program. This task was addressed by a committee previously formed under the direction of the National Academies' Board on Science, Technology, and Economic Policy (STEP) to carry out an assessment of government-industry partnerships. The Committee responsible for this analysis was not charged with a review of questions of principle with regard to the desirability of government-industry cooperation. Recognizing that partnerships are an integral part of the U.S. innovation system, the Committee has taken a pragmatic approach focusing its work on the operation and assessment of government-industry partnerships.[1]

Government-industry cooperation to achieve national goals has played a key role in U.S. economic development.[2] Continued U.S. leadership in technological

[1] The scope of the Committee's work is described in the Preface.

[2] See the overview of the history of government-industry collaboration in the Preface of this volume. As discussed in the Introduction, the U.S. government has played a significant and supportive role in advancing technological progress in industries ranging from aircraft and biomedicine to information technology and the Internet. The ATP is a public-private partnership to develop new technologies with broad applications. The program makes competitive awards on a cost-share basis to individual companies and larger awards to joint ventures.

progress is essential for the long-term growth of the domestic economy at a rising standard of living.[3] Substantial domestic U.S. investment in research and development—both public and private—is the prerequisite for sustaining U.S. economic growth in a global economy.[4] A leading role for the United States in the development and commercialization of new technologies is essential to the continued competitive success of U.S. industry in global markets. Governments around the world have recognized the importance of new technologies to their economies and have encouraged public-private partnerships to develop and anchor them within their national economies. The long-term goal of these programs is to achieve greater productivity growth through the creation of knowledge that can be applied to industrial processes, products, and services.[5] The logic behind government funding of certain types of R&D activities is that government awards provide incentives to firms to undertake high-risk R&D projects with substantial potential benefits for the economy as a whole.[6] In the middle of the 1980s the United States began focusing more attention on cost-shared partnerships as a means of developing new technologies.

As noted in the Introduction, the Committee's assessment of the Advanced Technology Program is contributing to the Committee's review of government-industry partnerships programs in the United States and abroad. This assessment of the ATP should thus be understood as one element of the Committee's multi-year study of a wide variety of partnerships. Carrying out this analysis of the ATP

[3] See Michael Borrus and Jay Stowsky, "Technology Policy and Economic Growth," in Lewis Branscomb and James Keller, editors, *Investing in Innovation: Creating a Research and Innovation Policy,* Cambridge, MA: MIT Press, 1998. The contribution of technology to economic growth is now well recognized. See P. Romer, "Endogenous Technological Change," *Journal of Political Economy*, 98(5):71-102, 1990. See also G. Grossman and E. Helpman, *Innovation and Growth in the Global Economy*, Cambridge, MA: MIT Press, 1993.

[4] Romer, "Endogenous Technological Change," *op. cit.*; Borrus and Stowsky, "Technology Policy and Economic Growth," *op. cit*. See also National Research Council, *Allocating Federal Funds for Science and Technology*, Washington, D.C.: National Academy Press, 1995. The report notes that federal investments in R&D have produced enormous benefits for the nation's economy, national defense, health, and social well-being. *Ibid*, p. 3.

[5] See the paper by Maryann P. Feldman and Maryellen R. Kelley, "Leveraging Research and Development: The Impact of the Advanced Technology Program," in this volume.

[6] As noted by Feldman and Kelley in this volume, "The logic for public investment is that, in the long run, the economic benefits to consumers, other firms and the larger national economy will exceed the private returns realized by the firm that received the research award, and thus justify the public investment." *Ibid*. The rationale for government funding of certain types of R&D activities, as articulated by Zvi Griliches, is that this funding encourages firms to undertake R&D projects in which the public rate of return exceeds the private rate of return. This includes, for example, the case in which an industry as a whole may benefit from the development of an enabling technology. Private firms typically use some predetermined benchmark rate of return known as a hurdle rate. The project will only be acceptable if the expected rate of return is above that benchmark. By reducing the cost of the project, government funding will increase the expected rate of return and may make private companies willing to pursue them. See Z. Griliches, "The Search for R&D Spillovers," *Scandinavian Journal of Economics*, 94(Supplement):29-47.

has informed the Committee's deliberations and allowed for comparative points of view on a range of partnership activities. As part of this assessment, the Committee organized two major symposia and a workshop to review the program's operation and also drew on the substantial body of independent analysis of the program. The initial symposium provided an overview of the program in terms of its goals, operations, assessment, achievements, and challenges while providing an opportunity for critics to voice their views. The symposium summarized in this volume focused on possible improvements to the program, findings from the ATP assessment effort, issues such as "crowding out" and the relationship of the ATP to venture capital, the roles and needs of large companies in such a program, and feedback from users, some of whom have received other types of awards. The collection of papers included in this volume provide insights into the operation and impact of the ATP and are illustrative of the substantial program of external and internal research it has under way. The meetings and research are of course complemented by the exceptional expertise of the Committee responsible for the NRC review of government-industry partnerships.[7] Keeping in mind the limitations and advantages of the Committee's analysis, the core findings and recommendations of the study are listed below.

CORE FINDINGS AND RECOMMENDATIONS[8]

1. The Committee finds that the Advanced Technology Program is an effective federal partnership program. The selection criteria applied by the program enable it to meet broad national needs and help ensure that the benefits of successful awards extend across firms and industries. Its cost-shared, industry-driven approach to funding promising new technological opportunities has shown considerable success in advancing technologies that can contribute to important societal goals such as improved health diagnostics (e.g., breast cancer detection), developing tools to exploit the human genome (e.g., colon cancer protection), and improving the efficiency and competitiveness of U.S. manufacturing.[9]

[7] The members of the Committee are listed in the front matter.

[8] These summary findings and recommendations are elaborated and documented in Chapter III of this volume. In addition to the papers and proceedings in this volume, the Committee issued National Research Council, *The Advanced Technology Program: Challenges and Opportunities*, Washington, D.C.: National Academy Press, 1999. The ATP assessment program also provides extensive documentation regarding the contributions of the program. See Annex D in this volume. See also William F. Long, *Advanced Technology Program: Performance of Completed Projects: Status Report Number 1*, NIST Special Publication 950-1, March 1999.

[9] See Section I in Chapter III of this volume. For a summary of the differentiating characteristics of the ATP, see Maryann Feldman's analysis in Section C of the Introduction and the study by Feldman and Kelley, "Leveraging Research and Development: The Impact of the Advanced Technology Program," both in this volume.

2. The program's peer review of applicants for both technical feasibility and commercial potential supports its goal of helping advance promising new technologies that are unlikely to be funded through the normal operation of the capital markets.[10]
3. The program has set a high standard for assessment involving both internal and independent external review. The quality of this assessment effort lends credence to the program's evaluation of its accomplishments.[11]
4. The extensive assessments of the program show that it appears to have been successful in achieving its core objective, that is, enabling or facilitating private sector R&D projects of a type, or in an area, where social returns are likely to exceed private returns to private investors.[12,13]

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[10] With regard to the ATP selection process see the presentation by former ATP Director, Lura Powell, in the first volume of this study, National Research Council, *The Advanced Technology Program: Challenges and Opportunities*, *op. cit*., pp. 53-56; with regard to the role of venture capital finance and the need for a bridging mechanism, see the statement by Todd Spener of Charter Financial in the same volume, pp. 90-91, as well as the presentation by Joshua Lerner of the Harvard Business School, pp. 88-90. See also the presentation by venture capitalist David Morgenthaler in Panel I of the Proceedings of this volume and the summary of his statement in Section C of the Introduction to this volume. See also Lewis M. Branscomb and Philip E. Auerswald, *Taking Technical Risks: How Innovators, Managers and Investors Manage Risk in High-Tech Innovation,* Cambridge: MIT Press, 2001, Chapter 5 and *passim*.

[11] See Section I in Chapter III of this volume and the description of the program, its current results, and the ATP assessment effort by Rosalie Ruegg and the positive review of the assessment program by Irwin Feller of Pennsylvania State University in Panel II in this volume. See also the panel discussion led by Richard Nelson of Columbia University, including the description of the ATP assessment, its early beginnings, and its focus on tools for assessing technology spillovers in National Research Council, *The Advanced Technology Program: Challenges and Opportunities*, *op. cit*., pp. 71-80.

[12] See, for example, the paper by Maryann Feldman and Maryellen Kelley, "Leveraging Research and Development: The Impact of the Advanced Technology Program," in this volume. The study by Albert N. Link, "Enhanced R&D Efficiency in an ATP-funded Joint Venture," documents the impact of an ATP joint venture designed to reduce the costs and timing required to develop a suite of new technologies for the U.S. printed wiring board industry. The study finds a dramatic effect on R&D efficiency, resulting in cost savings on the order of $35 million while reducing cycle times for new product and process development. The project resulted in productivity improvements for member companies, diffusion of new technology to other producers, and improved competitive positions for and retained employment at participating companies. The study by David Austin and Molly Macauley, "Estimating Future Benefits from ATP Funding of Digital Data Storage," estimates substantial consumer welfare gains from ATP-funded innovations in digital data storage although the final impact is dependent on the adoption of the technologies. Similarly, the paper by Tayler H. Bingham, "Estimating Economic Benefits from ATP Funding of New Medical Technologies," projects substantial social returns, much larger than the projects' private returns, primarily due to the projected positive spillovers to patients treated with new technologies. These technologies focus on the diagnosis and treatment of cancer; the treatment of diabetes, damaged ligaments and tendons; and the transplanting of xenogenic organs. The overview of the progress of ATP awards by Rosalie Ruegg, "Taking a Step Back: An Early Results Overview of Fifty ATP Awards," documents both commercialization progress and

5. The Committee does recommend a series of operational improvements designed to make this program more effective and suggests several measures designed to bring the benefits of the ATP to other national initiatives and to state technology programs through enhanced cooperation.[14]

knowledge creation and dissemination. The latter is documented through outside recognition of the project's technical accomplishments, patents filed and granted, patent-tree citations, collaborative relationships, and knowledge disseminated through new products and processes. Ruegg records substantial evidence that benefits are extending well beyond those captured by award recipients. The papers cited above are included in this volume.

[13] For an excellent review of the factors affecting the generation and impact of social returns or spillovers, see Adam B. Jaffe, *Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program,* NIST GCR 97-708, December 1996. For additional ATP-supported research on social benefits, see Edwin Mansfield, *Estimating Social and Private Returns from Innovations Based on the Advanced Technology Program: Problems and Opportunities,* NIST GCR 99-780, January 1996; William F. Long, *Performance of Completed Projects, Status Report Number 1*, *op. cit.*; Wesley M. Cohen and John Walsh, *R&D Spillovers, Appropriability, and R&D Intensity: A Survey-Based Approach,* Gaithersburg, MD: National Institute of Standards and Technology, Forthcoming; and Michael S. Fogarty, Amit K. Sinha, and Adam B. Jaffe, *ATP and the US Innovation System: A Methodology for Identifying Enabling R&D Spillover Networks with Application to Microelectro-mechanical Systems (MEMS) and Optical Recording,* Gaithersburg, MD: National Institute of Standards and Technology, Forthcoming.

[14] See Sections II and III in Chapter III of this volume.

I

PREFACE

Preface

The Advanced Technology Program (ATP) was created to fund government-industry partnerships to support the development of new technologies with potential applications across the American economy.[1] Established in 1988 under the Reagan Administration and first funded under the Bush Administration, it represented one element of the U.S. government's efforts to restore and enhance the competitiveness of the U.S. economy. It provides cost-shared, competitive grants to industry to support R&D on high-risk, cutting-edge technologies with broad commercial potential and societal benefit.[2]

Although the program began with substantial bipartisan support, in the mid-1990s it became embroiled in political controversy, partly as a result of its rapid expansion in the early years of the Clinton Administration. While new to the Advanced Technology Program, this controversy has long been an integral part of the American policy dialogue. Indeed, the appropriate role of government in the economy has been a source of debate in the United States from its very origins. The earliest articulation of the government's nurturing role with regard to the composition of the economy was Alexander Hamilton's 1791 *Report on*

[1] This volume is the second in a series on the Advanced Technology Program. The first volume, National Research Council, *The Advanced Technology Program: Challenges and Opportunities*, Washington, D.C.: National Academy Press, was released in October 1999. These reviews are part of a broader study, carried out by the National Research Council Board on Science, Technology, and Economic Policy, on *Government-Industry Partnerships for the Development of New Technologies*, described below.

[2] The grants are made in the form of cooperative agreement contracts. This is of key importance for it embodies a shared responsibility between the National Institute of Standards and Technology (NIST) and the firms for the evolution of the project.

Manufactures, in which he urged an activist approach by the federal government. At the time Hamilton's views were controversial, although subsequent U.S. policy has largely reflected his belief in the need for an active federal role in the development of the American economy.

EARLY PARTNERSHIPS

Driven by the exigencies of national defense and the requirements of transportation and communication across the American continent, the federal government has played an instrumental role in developing new production techniques and technologies. To do so, government has often turned to individual entrepreneurs with innovative ideas. For example, in 1798 the federal government laid the foundation for the first machine tool industry with a contract to the inventor, Eli Whitney, for interchangeable musket parts.[3] A few decades later, in 1842, a hesitant Congress appropriated funds to demonstrate the feasibility of Samuel Morse's telegraph.[4] Both Whitney and Morse fostered significant innovations that led to whole new industries. Indeed, Morse's innovation was the first step on the road toward today's networked planet.

The support for Morse's new invention was not an isolated case. The federal government increasingly saw economic development as central to its responsibilities. Examples of federal contributions to U.S. economic development abound. The government played a key role in the development of the U.S. railway network, the growth of agriculture through the Morrill Act (1862) and the creation of the agricultural extension service, and support of industry through the creation of the National Bureau of Standards in 1901.[5]

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[3] Whitney missed his first delivery date for the arms and encountered substantial cost overruns, a set of events that is still familiar. However, his focus on the concept of interchangeable parts, and the machine tools to make them, was prescient. In David A. Hounshell's excellent analysis of the development of manufacturing technology in the United States, he suggests that Simeon North was ultimately the most successful in achieving interchangeability and the production of components by special-purpose machinery. See *From the American System to Mass Production, 1800-1932*, Baltimore: Johns Hopkins University Press, 1985, p. 25-32. By the 1850s, the United States had begun to export specialized machine tools to the Enfield Arsenal in Great Britain. The British described the large-scale production of firearms, made with interchangeable parts, as "the American system of manufacturers." See David C. Mowery and Nathan Rosenberg, *Paths of Innovation: Technological Change in 20th Century America*, New York: Cambridge University Press, 1998, p. 6.

[4] For a discussion of Samuel Morse's 1837 application for a grant and the congressional debate, see Irwin Lebow, *Information Highways and Byways,* New York: IEEE, 1995, pp. 9-12. For a more detailed account see Robert Luther Thompson, *Wiring a Continent: The History of the Telegraph Industry in the United States 1823-1836*, Princeton, NJ: Princeton University Press, 1947.

[5] See Richard Bingham, *Industrial Policy American Style: From Hamilton to HDTV*, New York: M.E. Sharpe, 1998, for a comprehensive review. In the case of the transcontinental railroad, Stephen Ambrose describes Abraham Lincoln as the "driving force" behind its development. Lincoln was intimately involved, helping to decide the project's route, financing, and even the gauge of the tracks: *Nothing Like It in the World: The Men Who Built the Transcontinental Railroad, 1863-1869.* New York: Simon and Schuster, 2000.

Throughout the 20th century, the federal government had an enormous impact on the structure and composition of the economy through regulation, procurement, and a vast array of policies to support industrial and agricultural development. Between World War I and World War II, these policies included support for the development of key industries, with commercial and military applications, such as radios and aircraft frames and engines.[6] The requirements of World War II generated a huge increase in government procurement and support for high-technology industries. At the industrial level, there were "major collaborative initiatives in pharmaceutical manufacturing, petrochemicals, synthetic rubber, and atomic weapons."[7] An impressive array of weapons based on new technologies was developed during the war, ranging from radar and improved aircraft to missiles and, not least, the atomic bomb. Many of these military technologies found civilian applications after the war.

Both during and after the war, the government made unprecedented investments in computer technology.[8] During the war it played a central role in creating the first electronic digital computers, the ENIAC and the Colossus.[9] Following the war, the federal government began to fund basic research at universities on a significant scale, first through the Office of Naval Research and later through the National Science Foundation (NSF) and the Public Health Service.[10] At the same time, the continued reluctance of commercial firms, such as IBM and NCR to invest large sums in what they considered to be risky research and development projects with uncertain markets, forced the government to continue sponsoring the development of the new technology now referred to as computers.[11] In this early phase, the National Bureau of Standards [the precursor of the National Institute of Standards and Technology (NIST)] made a significant contribution,

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[6] See the Introduction to this volume.

[7] David Mowery, "Collaborative R&D: How Effective Is It?" *Issues in Science and Technology,* Fall 1998, p. 37.

[8] Kenneth Flamm, *Creating the Computer*, Washington, D.C.: The Brookings Institution, 1988, Chapters 1-3.

[9] For a detailed account of ENIAC's creation, see Scott McCartney, *ENIAC: The Triumphs and Tragedies of the World's First Computer*, New York: Walker and Company, 1999; and Flamm, *Creating the Computer*, *op. cit.,* p. 39.

[10] The National Science Foundation was initially seen as the agency that would fund basic scientific research at universities after World War II. However, disagreements over the degree of Executive Branch control over the NSF delayed passage of its authorizing legislation until 1950, even though the concept for the agency was first put forth in 1945 in Vannevar Bush's report, *Science: The Endless Frontier*. The Office of Naval Research bridged the gap in basic research funding during these years. For an account of the politics of the NSF's creation, see G. Paschal Zachary, *Endless Frontier: Vannevar Bush, Engineer of the American Century*, New York: The Free Press, 1997, p. 231. See also Daniel Lee Kleinman, *Politics on the Endless Frontier: Postwar Research Policy in the United States*, Durham, NC: Duke University Press, 1995. Computer science did not, however, mature as a separate academic discipline until the 1960s. In the interim, the military supported the fledgling computer industry on national security grounds.

[11] Flamm, *Creating the Computer*, *op. cit*., p. 75.

through its SEAC machine, to the development of the modern computer.[12] Throughout the Cold War, the United States continued to emphasize technological superiority as a means of ensuring U.S. security. Government funds and cost-plus contracts helped to support systems and enabling technologies such as semiconductors and new materials, radar, jet engines, advanced computer hardware and software, and missiles.

In the post-Cold War period, the evolution of the American economy continues to be profoundly marked by government-funded research in areas such as microelectronics, robotics, biotechnology and the human genome, and through earlier investments in communications networks such as ARPANET—the forerunner of today's Internet.

THE ROLE OF THE BOARD ON SCIENCE, TECHNOLOGY, AND ECONOMIC POLICY

Since 1991 the National Research Council's Board on Science, Technology, and Economic Policy (STEP) has undertaken a program of activities to improve policy makers' understanding of the interconnections of science, technology, and economic policy and their importance for the American economy and its international competitive position. The Board's activities have corresponded with increased recognition by policy makers of the importance of technology to economic growth. The new economic growth theory emphasizes the role of technology creation, which is believed to be characterized by significant growth externalities.[13] A consequence of the renewed appreciation of growth externalities is recognition of the economic geography of economic development. With growth externalities coming about in part from the exchanges of knowledge among innovators, certain regions become centers for particular types of high-growth activities.[14]

Some economic analysis suggests that high technology is often characterized

[12] As Kenneth Flamm observes, besides being the first operational von-Neumann-type stored-program computer in the United States, the Bureau of Standards' SEAC, or Standards Eastern Automatic Computer, pioneered important technology concepts. All of the logic was implemented with newly developed germanium diodes (10,000 were used); the vacuum tubes within (750) were only for providing power and electrical pulse-shaping circuitry. The computer also used standardized, replaceable circuit modules, an innovation soon adopted throughout the industry. Thus the first computer to use solid state logic was also the first modern computer to be completed in the United States. Flamm, *Creating the Computer*, *op. cit*., p. 74.

[13] Paul Romer, "Endogenous Technological Change," *Journal of Political Economy,* 98(5):71-102, 1990. See also Gene Grossman and Elhanan Helpman, *Innovation and Growth in the Global Economy,* Cambridge, MA: MIT Press, 1993.

[14] Paul Krugman, *Geography and Trade*, Cambridge, MA: MIT Press, 1991, p. 23, points out how the British economist Alfred Marshall initially observed in his classic, *Principles of Economics,* how geographic clusters of specific economic activities arose from the exchange of "tacit" knowledge among businesses.

by increasing rather than decreasing returns, justifying to some the proposition that governments can capture permanent advantage in key industries by providing relatively small but potentially decisive support to bring national industries up the learning curve and down the cost curve.[15] In part, this is why the economic literature now recognizes the relationship between technology policy and trade policy.[16] Recognition of these linkages and the corresponding ability of governments to shift comparative advantage in favor of the national economy provides intellectual underpinning for government support for high-technology industry.[17] Another widely recognized rationale for government support for high technology exists in cases in which technology generates benefits beyond those that can be captured by innovating firms, often referred to as spillovers.[18] There are also cases in which the cost of a given technology may be prohibitive for individual companies, even though expected benefits to society are substantial and widespread.[19] Both of these propositions are central to the mission of the Advanced Technology Program.

PROJECT ORIGINS

The growth in government programs to support high-technology industry within national economies and their impact on international science and technology cooperation and on the multilateral trading system are of considerable interest worldwide. Accordingly, these topics were taken up by STEP in a study carried

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[15] Paul Krugman, *Rethinking International Trade*, Cambridge, MA: MIT Press, 1990.

[16] In addition to Krugman, see J. A. Brander and B. J. Spencer, "International R&D Rivalry and Industrial Strategy," *Review of Economic Studies,* 50(4):707-722, 1983, and "Export Subsidies and International Market Share Rivalry," *Journal of International Economics*, 18(1-2):83-100, 1985. See also A. K. Dixit and A. S. Kyle, "The Use of Protection and Subsidies for Entry Promotion and Deterrence," *American Economic Review,* 75(1):139-152, 1985, and P. Krugman and M. Obstfeldt, *International Economics: Theory and Policy,* 3rd ed., New York: Addison-Wesley Publishing Company, 1994.

[17] For a review of governments' efforts to capture new technologies and the industries they spawn for their national economies, see National Research Council, *Conflict and Cooperation in National Competition for High-Technology Industry,* Washington, D.C.: National Academy Press, 1996, pp. 28-40. For a critique of these efforts see P. Krugman, *Peddling Prosperity,* New York: W. W. Norton Press, 1994.

[18] See, for example, Martin N. Baily and A. Chakrabarti, *Innovation and the Productivity Crisis,* Washington, D.C.: The Brookings Institution, 1998; and Zvi Griliches, *The Search for R&D Spillovers,* Cambridge, MA: Harvard University Press, 1990.

[19] See Ishaq Nadiri, *Innovations and Technological Spillovers,* NBER Working Paper No. 4423, 1993; and Edwin Mansfield, "Academic research and industrial innovation," *Research Policy,* 20(1):1-12, 1991. See also, Council of Economic Advisers, *Supporting Research and Development to Promote Economic Growth: The Federal Government's Role,* Washington, D.C.: Executive Office of the President, 1995.

out in conjunction with the Hamburg Institute for Economic Research (HWWA) and the Institute for World Economics (IFW) in Kiel.[20] One of the principal recommendations for further work emerging from that study was a call for an analysis of the principles of effective cooperation in technology development. These analyses would include lessons from national and international consortia, such as assessment mechanisms and modes of cooperation that might be developed to improve national and international cooperation in high-technology products.[21]

PROJECT PARAMETERS

To advance our understanding of the operation and performance of partnerships, the STEP Board has undertaken a major study of programs relying on public-private collaboration for the development of new technologies. The project's multidisciplinary Steering Committee[22] includes members from academia, high-technology industries, venture capital firms, and the realm of public policy. The intent of the study is not to address general questions of principle regarding the appropriateness of government involvement in partnerships. Instead, the Committee's charge is to take a pragmatic approach to address such issues as the rationale and organizing principles of government-industry cooperation to develop new technologies, current practices, sectoral differences, means of evaluation, the experience of foreign-based partnerships, and the roles of government laboratories, universities, and other non-profit research organizations.

As a program-based assessment of partnerships, focusing on best practices rather than issues of principle, the study has given particular attention to generic partnership programs such as the Small Business Innovation Research Program (SBIR) and ATP and the needs emerging from the growth in health-related fund-

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[20] This study resulted in two National Research Council reports: *Conflict and Cooperation, op. cit.*, and *International Friction and Cooperation in High-Technology Development and Trade*, Washington, D.C.: National Academy Press, 1997. A third report was published by the German HWWA, Georg Koopmann and Hans-Eckart Scharrer, editors, *The Economics of High-Technology Competition and Cooperation in Global Markets,* Baden-Baden: HWWA (Institute for Economic Research), 1996.

[21] The NRC report, *Conflict and Cooperation*, *op. cit*., recommends further analytical work concerning principles for effective cooperation in technology development (see Recommendation 24, p. 8). David Mowery of the University of California at Berkeley has recently noted the rapid expansion of collaborative activities and emphasized the need for comprehensive assessment. David Mowery, "Collaborative R&D: How Effective is it?" *op. cit*., p. 44. See also David Mowery, "Using Cooperative Research and Development Arrangements as S&T Indicators: What do We Have and What Would We Like?" Presentation before National Science Foundation conference, *Workshop on Strategic Research Partnerships*, 13 October 2000. Publication of proceedings pending.

[22] For the Committee membership, see the front matter of this volume.

ing and the relative decline in R&D support in other areas such as information technologies. A series of intermediate reports on these programs and topics will contribute to the preparation of the Committee's final report. That report will recommend best practice principles of operation both for national programs and for international collaboration.

The Committee's analysis has included a significant but necessarily limited portion of the wide variety of cooperative activity that takes place between the government and the private sector.[23] The selection of specific programs to review has been conditioned by the Committee's desire to carry out an analysis of current partnerships directly relevant to contemporary policy making. The Committee also recognizes the importance of placing each of the studies in the broader context of U.S. technology policy, which continues to employ a wide variety of ad hoc mechanisms developed through the government's decentralized decision-making and management process.

The Committee's desire to ensure that its deliberations and analysis are directly relevant to current policy making has allowed it to be responsive to requests from the Executive Branch, and to requests by Congress, for an examination of various policies and programs of current policy relevance. These would include the White House and State Department request for an evaluation of opportunities for greater transatlantic cooperation as a result of the signature of the U.S.-E.U. Agreement on Science and Technology Cooperation, the request by the Defense Department's Under Secretary for Technology and Acquisitions to review the Fast Track initiative in the SBIR program at the Department of Defense, and of course this assessment of the Advanced Technology Program, requested by NIST in compliance with Senate Report 105-235.[24] The Committee has also focused its attention on the emerging needs, synergies, and opportunities between the fields of biotechnology and computing, with special attention directed to the differences and similarities of government support for technology development in biotechnology and computing, the different uses of intellectual property in these sectors, and the need for balanced investments across disciplines. To meet its proposed objectives, the study has focused on the assessment of current and proposed programs, drawing on the experience of previous U.S. initiatives, foreign practice, and emerging areas (e.g., bioinformatics) resulting from U.S. investments in advanced technologies. A summary of the partnerships taken up by the study are included in Box A.

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[23] For example, DARPA's programs and contributions have not been reviewed. For an indication of the scope of cooperative activity, see C. Coburn and D. Berglund, *Partnerships: A Compendium of State and Federal Cooperative Technology Programs,* Columbus, OH: Battelle Press, 1995; and the RaDiUS database, www.rand.org/services/radius/.

[24] See Senate Report 105-235, Departments of Commerce, Justice, and State, the Judiciary, and Related Agencies Appropriation Bill, 1999. Report from the Committee on Appropriations to accompany bill S. 2260, which included the Commerce Department FY1999 Appropriations Bill.

Box A. Partnerships Reviewed by the *Government-Industry Partnerships* Study

The NRC study of *Government-Industry Partnerships for the Development of New Technologies* has reviewed a wide range of partnerships. The study can be divided into four primary areas: analysis of current U.S. partnership programs, potential partnerships, industry-national laboratory partnerships, and international collaboration and benchmarking. The analysis of current U.S. partnerships has focused on the Small Business Innovation Research Program, the Advanced Technology Program, and partnerships in biotechnology and computing. The review of potential partnerships for specific technologies, based on the project's extensive generic partnerships analysis, has focused on needs in biotechnology and computing and opportunities for solid-state lighting. The industry-laboratory analysis reviewed the potential of science and technology parks at Sandia National Laboratories and NASA Ames Research Center. International collaboration and benchmarking studies have included outlining new opportunities resulting from the U.S.-E.U. Science and Technology Agreement and a review of regional and national programs to support the semiconductor industry, focusing on Japan, Europe, Taiwan, and the United States.

SUPPORT FOR ANALYSIS OF COOPERATIVE PROGRAMS

There is broad support for this type of objective analysis among federal agencies and the private sector. Government agencies supporting this analysis include the Department of Defense, the Department of Energy, the National Science Foundation, the National Institutes of Health, especially the National Cancer Institute and the National Institute of General Medical Sciences, the National Aeronautics and Space Administration, the Office of Naval Research, and the National Institute of Standards and Technology. Sandia National Laboratories and the Electric Power Research Institute have also contributed. Private support is provided by a diverse group of private corporations. All sponsors are listed in the front matter.

COMMISSIONED RESEARCH, WORKSHOPS, SYMPOSIA, AND DISCUSSIONS

This assessment of the ATP is best understood in the context of the Committee's analysis of government-industry partnerships. This report is derived from a two-year study of a wide variety of partnerships that has informed the Committee's deliberations and allowed for comparative points of view on a range of partnership activities.

In carrying out its analysis of the ATP, and to complement its own substantial expertise, the Committee commissioned independent research and convened a series of fact-finding meetings in the form of workshops and symposia. The summary of the April 2000 symposium on the Advanced Technology Program, included in this volume, represents one element of this fact-finding effort. The symposium is the third in a series of fact-finding meetings on the ATP convened under the auspices of the project on *Government-Industry Partnerships for the Development of New Technologies,*[25] and under the direction of the Steering Committee, to provide the basis for a review of the operation of this relatively small yet high-profile partnership program.[26]

The first conference brought together NIST officials, users (i.e., award winners), critics, and analysts. The report resulting from the conference provided valuable background information that provided a rare overview of the program in terms of its goals, operations, assessment, achievements, and challenges, while also providing an opportunity for well-known critics to voice their views. The second meeting was a workshop designed to provide a strategic assessment with regard to the program. The third conference focused more on operational improvements, the assessment program, issues such as "crowding out" and the relationship of the ATP to venture capital, the roles and needs of large companies in such a program, and feedback from users who have received other types of awards.

This report, which results from the third conference, provides substantial new information about the program and serves as a vehicle for the Committee's findings and recommendations. It includes descriptions of the policy context and study origins and an introduction that provides information about the program, a summary of the proceedings, and a summary of the analytical papers. The core of the report is the Committee's formal recommendations and findings on the operations of the ATP. The report also includes a summary of the proceedings from the third conference, which provides considerable tacit knowledge about the ATP. The inclusion of the discussion also permits convenient reference for the reader.

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[25] The first meeting of this series resulted in the National Research Council report, *The Advanced Technology Program: Challenges and Opportunities*, *op. cit*. Publications of the government-industry partnerships project include: National Research Council, *The Small Business Innovation Research Program: Challenges and Opportunities*, Washington, D.C.: National Academy Press, 1999; National Research Council, *Industry-Laboratory Partnerships: A Review of the Sandia Science and Technology Park Initiative,* Washington, D.C.: National Academy Press, 1999; National Research Council, *New Vistas in Transatlantic Science and Technology Cooperation,* Washington, D.C.: National Academy Press, 1999; National Research Council, *The Small Business Innovation Research Program: An Assessment of the Department of Defense Fast Track Initiative,* Washington, D.C.: National Academy Press, 2000; National Research Council, *A Review of the New Initiatives at the NASA Ames Research Center,* Washington, D.C.: National Academy Press, 2001.

[26] In comparison, the SBIR program, for example, is five times larger. Funded through a 2.5% set-aside on U.S. research agencies' budgets, SBIR is currently funded at approximately $1.2 billion per year. That amount will rise with expected increases in agency R&D budgets.

A collection of papers, which underscores the diversity of the research undertaken through the ATP assessment program, is included as is a bibliography for those interested in further information on this program and related topics.

ACKNOWLEDGEMENTS

A number of individuals deserve recognition for their contributions to the preparation of the report. On behalf of the STEP Board, we would like to express special recognition to NIST's Alan Balutis and Marc Stanley, the former and Acting Directors of the Advanced Technology Program, and Rosalie Ruegg, the former Director of the Office of Economic Assessment, now retired. Their interest and commitment to an objective review of this program are in the best tradition of federal service. They provided many valuable insights into the operation, assessment, and evolution of the program. We would also like to thank Johns Hopkins University's Maryann Feldman for her important contributions to our understanding of the operation of the Advanced Technology Program and Albert Link of the University of North Carolina at Greensboro for his analysis of the impact of a major joint venture and his many insights on partnerships. Among the STEP staff, particular recognition is due to Duncan Brown for his excellent work in preparing the draft symposium summary. Special recognition and thanks are owed to David Dierksheide and McAlister Clabaugh for their instrumental role in organizing the April 25th conference (amid several others) and their many contributions in assembling, editing—and editing again—the seven papers and the presentations of some 20 speakers. Without their energy, enthusiasm, and commitment this report could not have been completed in the requisite time frame. Their contributions are in the best tradition of the Academies.

NRC REVIEW

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: Robert Archibald, College of William & Mary; David Audretsch, Indiana University; Lewis Branscomb, Harvard University; W. F. Brinkman, Bell Labs; Irwin Feller, Pennsylvania State University; Mary Good, Venture Capital Investors; Henry Kelly, Federation of American Scientists; Sam Kortum, Boston University; Charles Larson, Industrial Research Institute; Lori Nye, Moore Technologies; Ariel Pakes, Harvard University; Henry Petronski, Duke University; James Serum, Viaken Systems; Scott Stern, Massachusetts Institute of Technology; Robert White, Carnegie Mellon University; and Loren Yager, U.S. General Accounting Office.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Gerald P. Dinneen, Honeywell, Inc. (retired); and Christopher A. Sims, Princeton University. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Given the quality and number of presentations at this second symposium, summarizing the proceedings was a challenge. Every effort was made to capture the main points made during presentations and ensuing discussions, within the constraints imposed by the nature of a symposium summary. We apologize in advance for inadvertent errors and omissions in the summary. We also take this opportunity to thank our speakers, participants, and researchers for making their experience and expertise available to the STEP Board's analysis of the Advanced Technology Program.

STRUCTURE

This volume is divided into five main chapters. These include the Preface, Introduction, and Findings and Recommendations, which are the collective responsibility of the Steering Committee; the conference proceedings, which summarize the views of the conference participants; and a series of seven papers prepared for this volume, which were subject to close editing but remain the responsibility of the authors. Several of the papers are summaries of substantially larger studies carried out under the auspices of the ATP's evaluation program.

The goal of this volume is to advance our understanding of the ATP, in particular the results of its assessment program, and the impact of its awards. Unlike the first volume in this series, in this report the Committee describes its findings concerning the operation of the program and makes specific recommendations concerning new initiatives and possible improvements. This analysis also represents an important stage in the Committee's review of government-industry partnerships and the means of their assessment. By reviewing the program objectives, its selection process, and the impact of its awards, we hope to further public understanding of the program's contribution and constraints in bringing the fruits of American research to the marketplace.

Gordon M. Moore Charles W. Wessner

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II

INTRODUCTION

Introduction

The Introduction is divided into three main parts. The first is a background section summarizing the policy context that led to the development of the Advanced Technology Program (ATP) and a description of the program itself. The second part is a summary of the independent papers prepared for this volume. The third is a summary of the highlights of the symposium organized as part of the National Research Council (NRC) review of the ATP.[1]

A. BACKGROUND

At this writing, the American economy continues to enjoy steady growth, with inflation under tight control, unemployment at historically low levels, and productivity at higher levels than previous decades.[2] It is hard to remember that only 10 years ago many thought the American economy had been surpassed by the combination of patient capital, skilled engineering, and protected domestic markets that characterized the Japanese and other Asian economies. In the 1970s and 1980s, the United States recorded slow economic growth relative to post-war

[1] This is the second report on the ATP issued as part of the NRC review. For an explanation of the project, its origins, and areas of focus, see the Preface.

[2] Productivity increased after 1995. There is some debate about its sources and sustainability. See Dale Jorgenson and Kevin Stiroh, "Raising the Speed Limit: U.S. Economic Growth in the Information Age," *Brookings Papers on Economic Activity*, 2000, pp. 125-235. See also Robert Gordon, "Has the 'New Economy' Rendered the Productivity Slowdown Obsolete?" Manuscript. Northwestern University. June 12, 1999. See also Council of Economic Advisors, *Economic Report of the President*, Washington, D.C.: U.S. Government Printing Office, January 2001, ch. 1, especially pp. 25-32.

norms, sluggish productivity performance, and a loss of global market share and technological leadership in key U.S. industries, from steel and automobiles to televisions and semiconductors. There was also considerable concern about a rapidly rising trade deficit.[3] The causes of America's sub-par economic performance defied definitive analysis, but dire warnings of U.S. economic decline and the "deindustrialization" of key manufacturing sectors proliferated.[4] U.S. trade competitors, such as Japan, seemed to have developed an effective economic model different in important respects from what Americans believed to be the traditional laissez-faire American approach.[5] A key feature of that model was its emphasis on cooperation between government and industry rather than competition. The ability of different arms of Japanese industry to work with one another, and the close relationship between government and industry in supporting key economic sectors, had created substantial benefits for the Japanese economy.[6]

New Cooperative Programs and Policies

A series of public and private initiatives in the 1980s demonstrate the renewed emphasis on cooperation in U.S. public policy, especially a number of major legislative initiatives passed by the Congress. These included the Stevenson-

[3] This too has changed. In most quarters, there seems to be little concern about the trade deficit, although it continues to increase. For an analysis of the sustainability of the deficit, see Catherine Mann, *Is the U.S. Trade Deficit Sustainable?* Washington, D.C.: Institute for International Economics, 1993. The U.S. Trade Deficit Review Commission was established in October 1998 to review the trade deficit and its implications for the economy as a whole. See http://www.ustrdc.gov.

[4] Questions persist concerning the degree of the U.S. decline in the 1980s, just as questions remain concerning the sustainability of the current recovery. The STEP Board has recently completed a review of the competitive resurgence of the U.S. economy. It includes an assessment of the factors that have contributed to the U.S. recovery with a focus on eleven U.S. manufacturing and service sectors. See National Research Council, *U.S. Industry in 2000: Studies in Competitive Performance,* D. Mowery, editor, Washington, D.C.: National Academy Press, 1999.

[5] For a discussion of the different economic and cultural assumptions underpinning these differences, see Clyde V. Prestowitz, *Trading Places*, New York: Basic Books, 1988, Chapter 5; and James Fallows, *Looking at the Sun: The Rise of the New East Asian Economic and Political System*, New York: Pantheon Books, 1994, Chapter 4, pp. 194, 210. For an overview of these issues see National Research Council, *Conflict and Cooperation in National Competition for High-Technology Industry*, Washington, D.C.: National Academy Press, 1996, pp. 12-40. For a review of the main features of the East Asian economic success story, see World Bank, *The East Asian Economic Miracle: Economic Growth and Public Policy,* Policy Research Report, New York: Oxford University Press, 1993.

[6] For the best early analysis of the Japanese approach, see Chalmers Johnson, *MITI and the Japanese Miracle: The Growth of Industrial Policy 1925-1975,* Stanford, CA: Stanford University Press, 1982. See also D. T. Okimoto, "The Japanese Challenge in High Technology Industry," in National Research Council, *The Positive Sum Strategy*, R. Landau and N. Rosenberg, editors, Washington, D.C.: National Academy Press, 1986; and D. T. Okimoto, *MITI and the Market: Japanese Industrial Policy for High Technology Industry*, Stanford, CA: Stanford University Press, 1989.

Wydler Technology Innovation Act (1980), the Bayh-Dole University and Small Business Patent Act (1980), the Small Business Innovation Development Act (1982), the National Cooperative Research Act (1984), the Federal Technology Transfer Act (1986), the Omnibus Trade and Competitiveness Act (1988), the National Competitiveness Technology Transfer Act (1989), and the Defense Conversion, Reinvestment, and Transition Assistance Act (1992). These acts are summarized in Box B.

Box B. Principal Federal Legislation Related to Cooperative Technology Programs[7]

- **Stevenson-Wydler Technology Innovation Act (1980)** Required federal laboratories to facilitate the transfer of federally owned and originated technology to state and local governments and the private sector. The Act includes a requirement that each federal lab spend a specified percentage of its research and development budget on transfer activities and that an Office of Research and Technology Applications (ORTA) be established to facilitate such transfer.
- **Bayh-Dole University and Small Business Patent Act (1980)** Permitted government grantees and contractors to retain title to federally funded inventions and encouraged universities to license inventions to industry. The Act is designed to foster interaction between academia and the business community. This law provides, in part, for title to inventions made by contractors receiving federal R&D funds to be vested in the contractor if they are small businesses, universities, or not-for-profit institutions.
- **Small Business Innovation Development Act (1982)** Established the Small Business Innovation Research (SBIR) Program within the major federal R&D agencies to increase government funding of research with commercialization potential in the small high-technology company sector. Each federal agency with an R&D budget of $100 million or more is required to set aside a certain percentage of that amount to finance the SBIR effort.
- **National Cooperative Research Act (1984)** The National Cooperative Research Act of 1984 eased antitrust penalties on cooperative research by instituting single, as opposed to treble, damages for antitrust violations in joint research. The Act also mandated a “rule of reason” standard for assessing potential antitrust violations for cooperative research. This contrasted with the per se standard by which

[7] Drawn, with National Research Council modifications, from Christopher Coburn and Dan Berglund, *Partnerships: A Compendium of State and Federal Cooperative Technology Programs,* Columbus, OH: Battelle Press, 1995, p. 485.

(Continued)

any R&D collusion was an automatic violation, regardless of a determination of economic damage.

- **Federal Technology Transfer Act (1986)** Amended the Stevenson-Wydler Technology Innovation Act to authorize Cooperative Research and Development Agreements (CRADAs) between federal laboratories and other entities, including state agencies.
- **Omnibus Trade and Competitiveness Act (1988)** In addition to establishing a Competitiveness Policy Council designed to enhance U.S. industrial competitiveness, the Act created several new programs (e.g., the Advanced Technology Program and the Manufacturing Technology Centers) housed in the Department of Commerce's National Institute of Standards and Technology and intended to help accelerate development, commercialization, and application of promising new technologies and improve manufacturing techniques of small and medium-sized manufacturers.
- **National Competitiveness Technology Transfer Act (1989)** Part of the Department of Defense authorization bill, this act amended the Stevenson-Wydler Act to allow government-owned, contractor-operated laboratories to enter into cooperative R&D agreements.
- **Defense Conversion, Reinvestment, and Transition Assistance Act (1992)** Initiated the Technology Reinvestment Program (TRP) to establish cooperative, interagency efforts that address the technology development, deployment, and education and training needs within both the commercial and defense communities.

The Demise of Spin-offs

Another element in the economic and policy landscape at the time was the demise of the "spin-off" paradigm in defense procurement.[8] For years it was believed that investments in sophisticated defense systems had beneficial spillovers into commercial markets. Companies that developed and manufactured high-technology armaments were believed to be building a technological base that would enable them to compete effectively in commercial markets.[9] For a number of reasons—from burdensome government procurement regulations to

[8] For a discussion of the demise of the spin-off paradigm, see John Alic et al., *Beyond Spinoff: Military and Commercial Technologies in a Changing World*, Boston: Harvard University Press, 1992.

[9] In some cases, such as aircraft and computing in the early years, this assumption did hold. See National Research Council, *U.S. Industry in 2000, op. cit.*, pp. 184-189, and National Research Council, *Funding a Revolution: Government Support for Computing Research,* Washington, D.C.: National Academy Press, 1999, *passim*.

accelerating time-to-market demands in commercial markets—this paradigm no longer applied by the 1980s.[10] In fact, it was becoming obvious that firms competitive in commercial markets are often better able than firms with only military customers to provide defense systems with the most advanced capabilities, particularly in rapidly evolving sectors such as semiconductors.[11] Policy makers were therefore searching for ways to improve private-sector commercialization rates, primarily to enhance U.S. competitiveness, but ultimately for national security reasons as well.

Increased Cooperation

One of the strategies adopted by the United States in response to its perceived loss in competitiveness, at least in some sectors, was to encourage greater cooperation among industry and between industry and government. Such collaboration was by no means novel in the U.S. economy.[12] As noted in the Preface, government funds had supported the demonstration and development of the telegraph in the 19th century, and after World War I the federal government fostered an independent radio industry.[13] The federal government also provided active support through a variety of mechanisms for military and civil aviation and

[10] Some analysts argue that the U.S. defense acquisition system, sometimes accused of providing disguised subsidies for commercial industry, has in fact created disincentives and barriers to the operation of market forces. These include "the unique government oversight requirements, the unique procurement requirements, (and) the unique military specifications" associated with military procurement. See the presentations of Jacques Gansler in National Research Council, *International Friction and Cooperation in High-Technology Development and Trade,* Charles W. Wessner, editor, Washington, D.C.: National Academy Press, 1997. See also Richard Samuels, *Rich Nation, Strong Army: National Security and the Technological Transformation of Japan*, Ithaca, NY: Cornell University Press, 1994.

[11] In response to changing procurement needs, the Clinton Administration adopted a "dual use" strategy for defense procurement. See National Research Council, *Conflict and Cooperation*, *op. cit.*, pp. 153-158. See also the presentations of Paul Kaminski and Jacques Gansler in National Research Council, *International Friction and Cooperation in High-Technology Development and Trade*, *op. cit.*, pp. 130-152.

[12] Private cooperation also expanded. For example, in 1983, fourteen companies—mostly computing manufacturers, but also semiconductor, aerospace, and defense firms—banded together to form the Microelectronics and Computer Technology Corporation (MCC). For a review of the origins of MCC and SEMATECH, see John Horrigan, "Cooperating Competitors: A Comparison of MCC and SEMATECH," Monograph, Washington, D.C.: National Research Council, 1999.

[13] Josephus Daniels, Secretary of the Navy during the Wilson Administration, appeared to feel that monopoly was inherent to the wireless industry, and if that were the case, he believed the monopoly should be American rather than British. Britain had dominated pre-war Atlantic wireless traffic as well as the undersea telegraph cable. By pooling patents, providing equity, and encouraging General Electric's participation, the Radio Corporation of America was created. It proved useful in the early 1940s. See Irwin Lebow, *Information Highways and Byways: From the Telegraph to the 21st Century,* New York: IEEE Press, 1995, pp. 97-98 and Chapter 12.

the electronics industry.[14] Yet the 1980s and early 1990s saw a conscious effort to expand cooperation, in part by using federal R&D funding more effectively to meet what were seen as unprecedented competitive challenges. As a recent study of federal support for the computer industry observed, most federal support for industry prior to the mid-1980s took the form of research grants or contracts for product development or procurement that often included substantial support for research.[15] In the latter half of the decade, a growing number of programs were established to benefit from partnerships among government, industry, and universities. These included (1) the Semiconductor Research Corporation, which pools industry and limited federal funding to support university research in semiconductors; (2) SEMATECH, which matched substantial federal and industry funding in a consortium of semiconductor manufacturers;[16] (3) NSF Engineering Research Centers that involve industry-university collaboration on engineering problems; (4) expanded Cooperative Research and Development Agreements (CRADAs), particularly at the Department of Energy; and (5) extramural programs at the National Institute of Standards and Technology (NIST).

Some of the other major federal partnerships of this period were the Department of Defense's Manufacturing Technology (MANTECH) Program; the Department of Transportation's Intelligent Vehicle Highway Systems (IVHS) Program and National Magnetic Levitation Initiative (MAGLEV); the National Science Foundation's Research Centers Program (which includes the Engineering Research Centers, the Industry/University Cooperative Research Centers, the Materials Research Science and Engineering Centers, and the Science and Technology Centers); and the Small Business Technology Transfer (STTR) Program.[17]

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[14] D. Mowery and N. Rosenberg, *Technology and the Pursuit of Economic Growth,* New York: Cambridge University Press, 1989, Chapter 7, especially pp. 181-194. The authors note that the commercial aircraft industry is unique among manufacturing industries in that a federal research organization, the National Advisory Committee on Aeronautics (NACA—founded in 1915 and absorbed by NASA in 1958), conducted and funded research on airframe and propulsion technologies. Before World War II, NACA operated primarily as a test center for civilian and military users. NACA made a series of remarkable contributions with regard to engine nacelle locations and the NACA cowl for radial air-cooled engines. These innovations, together with improvements in engine fillets based on discoveries at Caltech and the development of monocoque construction, had a revolutionary effect on commercial and military aviation. These inventions made the long-range bomber possible, forced the development of high-speed fighter aircraft, and vastly increased the appeal of commercial aviation. Lebow, *Information Highways and Byways, op. cit.*; and Alexander Flax, National Academy of Engineering, personal communication, September 1999.

[15] National Research Council, *Funding a Revolution, op. cit.*, pp. 32-33.

[16] In 1996, SEMATECH became a completely private-sector consortium. In 2000 it became International SEMATECH, a consortium that includes Asian and European companies.

[17] Coburn and Berglund, *Partnerships*, *op. cit*., p. 488. Other examples are listed in the Preface.

More Technology Opportunities, More Partnerships

In parallel with the competitive challenges facing the United States, rising development costs for new technologies, the dispersal of technological expertise across firms, and the growing importance of regulatory and environmental issues provided additional incentives for public-private cooperation in many high-technology industries. Reflecting these convergent trends, collaborative programs have expanded substantially, with perhaps as many as 70 federal cooperative technology programs currently under way.[18] This trend has continued across several administrations. It was under the Reagan Administration that, after much debate, SEMATECH was established in 1988 to address the competitive challenge facing the semiconductor industry.[19] As noted earlier, the first Bush administration oversaw the initial implementation of the Advanced Technology Program in the National Institute of Standards and Technology, and that administration recommended substantial increases for the program in its FY1993 budget.[20]

. . . and More Opposition

If the notion of additional government-industry collaboration was well developed by the late 1980s, it was by no means universally accepted. One of the earliest calls for increased collaboration, the President's Commission on Industrial Competitiveness, was released in 1983, but few of its recommendations were adopted.[21] The recommendations for expanded cooperation made by a subsequent study effort, the National Advisory Committee on Semiconductors (NACS), also met with limited success, although it served to highlight the importance of this strategic sector to the U.S. economy.[22] Even a broadly supported initiative such as SEMATECH, whose government funding in hindsight may have always

[18] *Ibid.,* p. 481.

[19] The Semiconductor Industry Association formally proposed the SEMATECH consortium in May 1987. In 1996 federal funding ceased. In early 2000 the consortium became International SEMATECH, with a global membership roster. For an overview of SEMATECH's early operation and contribution see National Research Council, *Conflict and Cooperation*, *op. cit.,* pp. 141-151. For one of the most comprehensive assessments of SEMATECH, see John B. Horrigan, "Cooperating Competitors: A Comparison of MCC and SEMATECH," *op. cit*.

[20] See the budget bar graph illustrating the evolution of program appropriations in Chapter III below.

[21] See President's Commission on Industrial Competitiveness, *Global Competition: The New Reality,* Washington, D.C.: U.S. Government Printing Office, 1985, 2 vols.

[22] See National Advisory Committee on Semiconductors, *Semiconductors: A Strategic Industry at Risk,* A Report to the President and the Congress, Washington, D.C.: Semiconductor Industry Association, 1989. See also National Advisory Committee on Semiconductors, *Toward a National Strategy for Semiconductors,* Washington, D.C.: Semiconductor Industry Association, 1991.

seemed secure, encountered serious opposition at its inception and again at its renewal.[23]

The Clinton Administration came to office with an emphasis on civilian technology programs, seeking to realign military and civilian R&D expenditures, and it encouraged the use of partnerships between government and industry to restore U.S. competitiveness.[24] As part of this effort, the Clinton Administration substantially expanded the ATP, created the Technology Reinvestment Program (TRP) to facilitate adjustment to the end of the Cold War, and established the Program for the Next Generation Vehicle (PNGV).[25] The rapid expansion of these programs generated significant opposition and may have contributed to the rekindling of the national debate on the appropriate role of the government in fostering new technologies.[26]

The Need for Analysis and Assessment

Despite the growth in government-industry collaboration, there has in fact been remarkably little objective analysis of these collaborative efforts. For example, even longstanding programs such as the Small Business Innovation Research (SBIR) Program, created in 1982, have seen very limited external evaluation.[27] At one level, more frequent analysis and review of the partnership

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[23] The 1992 renewal was undertaken in the era in which the President's economic advisors purportedly saw little difference between silicon chips (semiconductors) and potato chips. Today there is broader agreement that the composition of the economy matters and that high-technology industry has special benefits such as more rapid growth rates, greater R&D expenditure, and, often, higher wages as compared with more traditional industries.

[24] See William J. Clinton and Albert Gore, Jr., *Science in the National Interest*, Washington, D.C.: Executive Office of the President, 1994.

[25] For an overview of ATP see Christopher T. Hill, "The Advanced Technology Program: Opportunities for Enhancement," in Lewis Branscomb and James Keller, editors, *Investing in Innovation: Creating a Research and Innovation Policy,* Cambridge, MA: MIT Press, 1998, pp. 143-173. For an excellent analysis of the TRP, see Jay Stowsky, "Politics and Policy: The Technology Reinvestment Program and the Dilemmas of Dual Use," Mimeo, University of California, 1996. See also Linda R. Cohen, "Dual-use and the Technology Reinvestment Project," in Branscomb and Keller, *Investing in Innovation, op. cit*., pp. 174-193.

[26] As David Hart notes, opposition was both internal and external to the administration. Those members of the administration whose priority was to reduce the budget deficit scaled back support for public-private R&D. At the same time, some Members of Congress professed to believe that President Clinton and his party might reap political benefit from the ATP awards. Following the 1994 election, the new congressional majority opposed the Clinton technology policy initiatives and also called for the abolition of the Departments of Energy and Commerce. David M. Hart, *Forged Consensus: Science, Technology, and Economic Policy in the United States, 1921-1953*, Princeton: Princeton University Press, 1998, p. 230.

[27] The operations of the SBIR at the Department of Defense were recently reviewed by the Partnerships Program, and the PNGV has been subject to a regular review, also by the NRC. See National Research Council, *The Small Business Innovation Research Program: An Assessment of the Department of Defense Fast Track Initiative*, Charles W. Wessner, ed., Washington, D.C.: National Academy Press, 2000; and National Research Council, *Review of the Research Program of the Partnership for a New Generation of Vehicles: Sixth Report*, Washington, D.C.: National Academy Press, 2000.

programs under way might contribute to a better appreciation of the role of collaboration between government and industry in the development of the U.S. economy. Writing 20 years ago, one well-known American economist, Columbia University's Richard Nelson, observed that Americans are still remarkably uninformed about the long history of governmental policies aimed at stimulating innovation.[28] A recent comprehensive report on government support for computing research opens by stating that "It is difficult to recall and acknowledge" the federal government's major role in launching and sustaining the computer revolution, both in terms of innovation and infrastructure.[29] Today, many Americans seem to appreciate the contribution of new technologies to the robust economic growth of the past decade. Yet there is little evidence that Americans are aware of the contributions of federal support for technological innovation, from radio to computers to the Internet.[30]

In addition to a better understanding of how the U.S. economy developed and the role government has played in fostering that development, careful assessment of support for new technologies is necessary, because government intervention in the market can be fraught with risk. For example, as Roger Noll and Linda Cohen document, in the 1970s the federal government supported a number of large commercial demonstration projects, such as the Synthetic Fuels Corporation and the Clinch River Breeder Reactor. The government also provided substantial funds for the development of the Supersonic Transport. Several of these large-scale technology commercialization programs were sources of major frustration.[31]

Noll and Cohen describe the "political capture" of several of the large, commercial demonstration programs, which resulted in sustained funding even in the face of declining technical feasibility. Their analysis stresses the need for financial stability on one hand (a problem for the ATP, see below) and flexible man-

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[28] Otis L. Graham, *Losing Time: The Industrial Policy Debate,* Cambridge, MA: Harvard University Press, 1992, p. 250. Graham cites Richard Nelson's observations at the end of the Carter Administration; the situation may not have improved. Writing in 1994, James Fallows makes a similar observation. See *Looking into the Sun, op. cit.*, p. 196. See also Thomas McCraw's "Mercantilism and the Market: Antecedents of American Industrial Policy," in Claude E. Barfield and William A. Schambra, editors, *The Politics of Industrial Policy*, Washington, D.C.: American Enterprise Institute for Public Policy Research, 1986, pp. 33-62.

[29] National Research Council, *Funding A Revolution, op. cit.*, p. 1.

[30] *Ibid.*, pp. 85-135 and pp. 169-183. The report provides a thorough review of government support for computers, the Internet, and related technologies and infrastructure.

[31] See Linda R. Cohen and Roger G. Noll, *The Technology Pork Barrel,* Washington, D.C.: The Brookings Institution, 1991, pp. 97-148, 217-320. The volume is a valuable review of large-scale technology development programs drawn from the 1970s that is still relevant to current policy and commitments, such as fusion reactors and clean coal (p. 36). The analysis is more balanced than its title. In addition to major failures, the authors identify technically successful R&D projects, such as the photovoltaic electricity program (p. 363). The focus of the authors' analysis is not directed to cost-shared programs such as the ATP.

agement on the other hand, willing to accept project failures as a necessary condition for investments in new high-risk technologies. The authors do recognize the contributions of federal policy to the development of new technologies and, more generally, endorse the notion that if research and development are important to attaining national goals, then the adequacy of the R&D effort in the private economy is a matter of concern.[32]

Box C. R&D Programs: The Challenge for Policymakers

Seeking to ascertain the factors that lead to successful programs, Cohen and Noll suggest that "The core challenge to public officials is not only to find ways to organize and manage R&D programs so that they are free from large swings in annual expenditures, but also to be sensitive to the fact that because R&D projects are risky, some are likely to fail and should be cancelled or redirected in midstream."

—*The Technology Pork Barrel*, *op. cit.*, p. vii.

There are also cases of major success resulting from federal support.[33] A significant example, of course, is the computer and semiconductor industries, in which the Department of Defense served as a source of R&D funding and a reliable early buyer of products.[34] DARPA later partnered with the semiconductor producers to address a competitive and qualitative challenge with the SEMATECH consortium.[35] Sustained NIH support for new drugs and new medical devices has contributed to major improvements in health, and the mapping of the genome has transformed the prospects for drug development.

Because the development of new technologies is inherently risky, regular assessment is vital to ensure continued technical viability, with cost-sharing requirements acting as an effective safeguard. Assessment can also help avoid

[32] *Ibid*., pp. 3 and 17.

[33] *Ibid*. The authors identify defining technological successes such as computers, the Internet, hybrid seeds, and aircraft. See also Box G, discussing "Picking Winner and Losers," p. 51.

[34] Graham, *Losing Time, op. cit.*, p. 2.

[35] Market-opening measures, such as the Semiconductor Trade Agreement (SCTA), also played an important role in preventing dumping and improving market access for U.S. firms. For a review of the SCTA see National Research Council, *Conflict and Cooperation, op. cit.,* p. 81, note 211, and pp. 131-141. See also Kenneth Flamm, *Mismanaged Trade? Strategic Policy and the Semiconductor Industry,* Washington, D.C.: The Brookings Institution, 1996, Chapters 3, 4, and 5, especially pp. 279-293.

"political capture" of projects, especially large commercial demonstration efforts.[36] Even successful collaborations face the challenge of adapting programs to rapidly changing technologies.[37] Assessment thus becomes a means of keeping programs relevant. Assessment can also have the virtue of reminding policy makers of the need for humility before the "black box" of innovation. As one observer notes, "experience argues for hedged commitments, constant reappraisal, maintenance of options, and pluralism of advice and decision makers."[38]

Comparisons in a Global Economy

From an international perspective, understanding the benefits and challenges of programs to support industry is also important insofar as they have been, and remain, a central element in the national development strategies of both industrial and industrializing countries. Governments have shown a great deal of imagination in their choices of mechanisms designed to support high technology industries. They employ a wide range of policies from trade regulations designed to protect domestic products from foreign competition to tax rebates intended to stimulate the export of selected domestic products. Many provide government R&D funding for enterprises of particular interest and, as the chart below shows, a number of countries have substantially increased their expenditures on R&D. Major financial support is sometimes overtly provided through direct grants, loans, and equity investments; more opaque support can also be provided through mechanisms such as tax deferral.[39] Data collected by the Paris-based Organization for Economic Cooperation and Development (OECD) suggest that worldwide government expenditures on support for high-technology industries involve significant resources and are increasingly focused on what policy makers consider to be strategic industries.[40]

In the past decade, countries ranging from Taiwan to Finland to Japan have launched accelerated cooperative programs to restore or gain national competitive-

[36] Noll and Cohen stress that political capture by distributive congressional politics and industrial interests is one of the principal risks for large-scale, government-supported commercialization projects. In cases such as the Clinch River project, they extensively document the disconnect between declining technical feasibility and increasing political support. See Linda R. Cohen and Roger G. Noll, *The Technology Pork Barrel*, *op. cit*., p. vii and pp. 242–257.

[37] One of the strengths of SEMATECH was its ability to redefine goals in the face of changing conditions. See Grindley et al., "SEMATECH and Collaborative Research: Lessons in the Design of High-Technology Consortia," *Journal of Policy Analysis and Management,* 13(4):724, 1994. See also National Research Council, *Conflict and Cooperation, op. cit*., p. 148.

[38] Graham, *Losing Time*, *op. cit*., p. 251. Graham is referring to work by Richard R. Nelson in *Government and Technological Progress*. New York: Pergamon Press, 1982, pp. 454-455.

[39] For an overview of the policy goals and instruments, see National Research Council, *Conflict and Cooperation*, *op. cit*., Box B, pp. 39-40. See also Martin Brown, *Impacts of National Technology Programs,* Paris: OECD, 1995, especially Chapter 2.

[40] See Martin Brown, *Impacts of National Technology Programs, op. cit.*

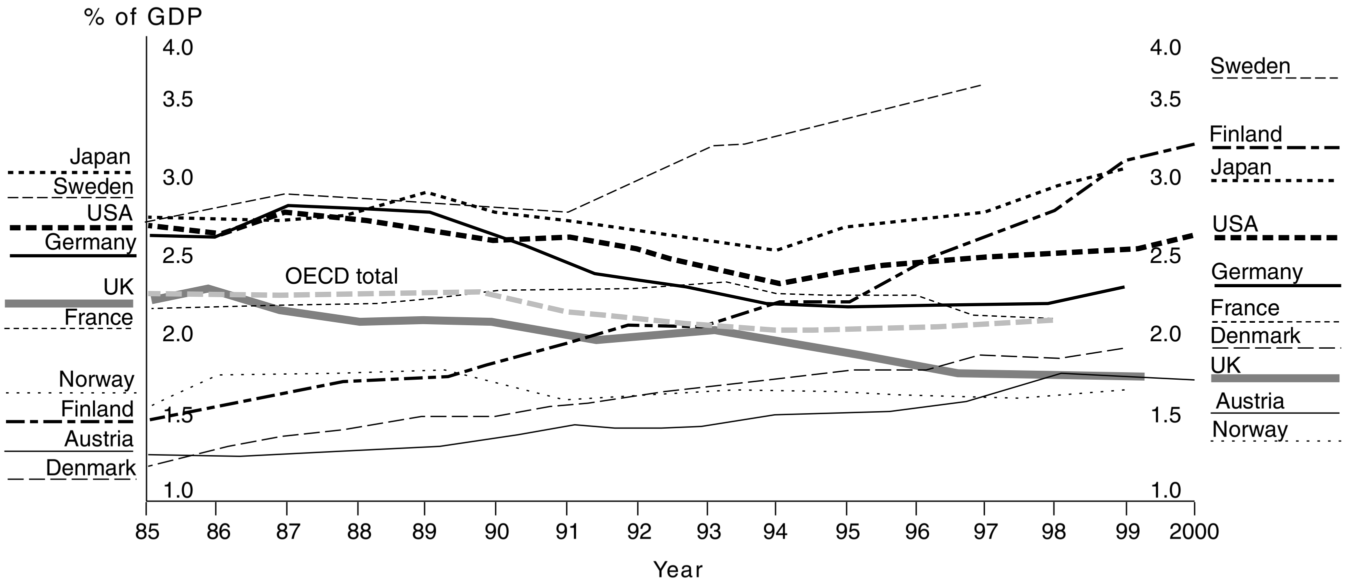

FIGURE National expenditure on R&D
Source: OECD, Main Science and Technology Indicators Database.

ness in key industries. Semiconductors and communications are frequent targets. The semiconductor industry, seen as an enabling or strategic sector, has long benefited from government support in this country and abroad.[41] In Japan and elsewhere, the SEMATECH consortium is seen as a major contribution to the resurgence of the American semiconductor industry.[42] Japan has launched an innovative series of public-private partnerships based in part on the SEMATECH model with the objective of restoring the competitive position of its semiconductor industry.[43] These cooperative activities are by no means confined to traditional competitors for high-technology industry. Finland has a more general program of technology development called Tekes, which brings together key elements of Finnish technology strategy under a single directorate. Parts of Finland's program have substantial similarities with the ATP. Reflecting the Finnish commitment to investments in new technologies, the Tekes program is funded at a similar level to the ATP. In 2000, Finland, a country of 5.1 million people, funded 2,297 research and development projects through Tekes for a total value of EUR 370 million as compared with the approximately $143 million appropriated to the ATP in FY2000.[44]

The United States is an active, if unavowed, participant in this global competition to support national industries, through both state and federal governments. Indeed, the United States has a remarkably wide range of public-private partnerships in high-technology sectors.[45] In addition to the well-known cases mentioned above, there are public-private consortia of many types. They can be classified in a number of ways, such as by the economic objective of the partnership—for example, leveraging the social benefits associated with federal R&D activity, enhancing the position of a national industry, or deploying industrial R&D to meet military or other government missions.[46] Partnerships can also be

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[41] "The semiconductor industry has never been free of the visible hand of the government intervention. . . . [T]he semiconductor industry, *wherever it has developed,* has been an explicit target of industrial policy—whether in the guise at military policy in the United States or in the guise at commercial policy elsewhere in the world" (original emphasis). Laura D'Andrea Tyson, *Who's Bashing Whom? Trade Conflict on High Technology Industries*, Washington, D.C.: Institute for International Economics, 1992, p. 85.

[42] "A major factor contributing to the U.S. semiconductor industry's recovery from this perilous situation [in the 1980s] was a U.S. national policy based around cooperation between industry, government, and academia." Hajime Susaki, Chairman of NEC Corporation, "Japanese Semiconductor Industry's Competitiveness: LSI Industry in Jeopardy," *Nikkei Microdevices,* December 2000.

[43] For a description of these and other national programs in Taiwan, Korea, and Europe, see Thomas Howell, "An Overview of Government Policy Measures in Microelectronics," Monograph, Washington, D.C.: National Research Council, 2001.

[44] See the Tekes website, http://www.tekes.fi/eng/information/stat00.html (March 2001). Around EUR 230 million of this funding was in the form of grants and loans aimed at company research and development projects and about EUR 140 million at university and research institution projects.

[45] See Coburn and Berglund, *Partnerships*, *op. cit.*

[46] See A. Link, "Public/Private Partnerships as a Tool to Support Industrial R&D: Experiences in the United States," paper prepared for the working group on Innovation and Technology Policy of the OECD Committee for Science and Technology Policy, Paris, 1998, p. 20.

differentiated by the nature of public support. Some partnerships involve a direct transfer of funds to an industry consortium. Others focus on the shared use of infrastructure, such as laboratory facilities. A partial list would include partnerships in sectors such as electronic storage, flat panel displays, turbine technologies, new textile manufacturing techniques, new materials, magnetic storage, next-generation vehicles, batteries, biotechnology, optoelectronics, and ship construction.

The scope of federal cooperative activity includes programs such as the national manufacturing initiative, the National Science Foundation's (NSF) Engineering Research Centers, NSF's Science and Technology Centers, NIST's Manufacturing Extension Partnership Program, and the multi-agency Small Business Innovation Research Program, among others. The SBIR is a substantial program, six times the size of the ATP, which is designed to draw on the innovative capacity of small firms and to further the ability of U.S. industry to capture the benefits of U.S. research.[47] University-industry cooperation is also on the upswing, with a significant percentage of university R&D now provided by industry. There are also innovative cooperative efforts such as the Semiconductor Industry Association's MARCO program.[48]

In addition, as noted above, the national laboratories now have extensive cooperative agreements with industrial firms in the form of Cooperative Research and Development Agreements. The Stevenson-Wydler Act of 1980 and the Technology Transfer Act of 1986 created this new mechanism for R&D collaboration. Amended in 1989 to allow industry-operated federal labs to participate, these laws (and high-level political interest) stimulated hundreds of CRADAs. Between 1989 and 1995, the Department of Energy alone signed more than 1,000 CRADAs.[49] The requirements of these agreements pose daunting challenges for small businesses, and a reduction of funding for this form of cooperation has resulted in substantial reduction in activity.[50] Nonetheless, this form of coopera-

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[47] The 1992 increase in the SBIR set-aside to 2.5 percent of participating agencies' R&D budgets significantly augmented the program's resources, which are now in excess of $1.2 billion per year. That increase was accompanied by greater emphasis on commercialization.

[48] Industry support of university research has been growing, from $1.45 billion in 1994 to $2.16 billion in 1999, an annual increase of nearly 10 percent. See Charles F. Larson, "The Boom in Industry Research," *Issues in Science and Technology*, 16(4):27.

[49] David Mowery, "Collaborative R&D: How Effective is It?" *Issues in Science and Technology,* 15(1):38. Cooperative research under these agreements expanded rapidly. At the same time, these programs face many criticisms: the agency focus on intellectual property (IP) rights can obstruct timely completion of negotiations—a genuine problem insofar as many CRADAs are concerned with near-term results.

[50] CRADAs also require a high-level of technical sophistication, so that partner firms must make significant investments to support inward transfer and application of results. The last condition suggests that small firms may not be able to participate without financial and business assistance. *Ibid.*, p. 43. Funding, and therefore the number of CRADAs, declined sharply in the late nineties. See Greg Linden, David Mowery, and Rosemarie Ziedonis, "National Technology Policy in Global Markets,"

tion continues to evolve, particularly with large firms, and is making significant technological contributions.[51]

Origins of the ATP

The Advanced Technology Program was conceived as one means of addressing heightened concern about U.S. competitiveness and a desire to ensure that the U.S. economy benefited from federal R&D investments through partnerships. The legislation establishing the ATP was part of the Omnibus Trade Act of 1988, a complex bill whose main objective was to provide policy instruments to address the rapidly growing U.S. trade deficit. The sponsor of the Advanced Technology Program initiative was Senator Ernest Hollings of South Carolina, and the initial appropriation was small, only $10 million for 1990.

Initiated as a means of funding high-risk R&D with broad commercial and societal benefits that would not be undertaken by a single company, either because the risk was too high or because a large enough share of the benefits of success would not accrue to the company for it to make the investment, the program lacked the straightforward national security rationale that had underpinned many post-war U.S. technology programs. It did, however, reflect a general trend away from purely mission-oriented research and development towards facilitating more broadly based technological advances. The program's goal is to facilitate the development and application of new, enabling technologies that individual firms would not or could not pursue on their own and thereby encourage the economic growth that comes from the commercialization and use of new technologies in the private sector.

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in Albert Link and Maryann Feldman, eds., *Innovation Policy in the Knowledge-based Economy*, Boston: Kluwer Academic Publishers, 2001, p. 312. Funding of CRADAs declined in the late nineties, from $346 million in 1995 to an estimated $94 million in 1999, and there was a corresponding drop from 1,700 CRADAs in FY1996 to a still significant 700 in FY1999. *Ibid.*

[51] A major advance in lithography was announced by Lawrence Livermore National Laboratory in April 2001 that will allow chip manufacturers to create circuits as small as 10 nanometers wide using extreme ultraviolet (EUV) lithography. This advance was made under a CRADA in which the government laboratories provided facilities and expertise while the private companies such as Intel, AMD, Motorola, and Infineon provided funding and their own expertise. Interestingly, this success drew, in part, on an early ATP project with Lucent Technologies and Bell Laboratories, which significantly improved the accuracy of precision reflective optics, critical for EUV lithography. Beyond the state of the art when the award was made, this high-risk project aimed to find out whether the mirrors constituted a technical barrier that could not be surmounted. This project illustrates that a lack of immediate commercialization does not mean that the new technology will not eventually yield large benefits. William F. Long, *Advanced Technology Program: Performance of Completed Projects—Status Report Number 1,* NIST Special Publication 950-1, March 1999, pp. 75-77.

Box D. What is the Advanced Technology Program?

A Cost-shared, Industry-driven Technology Development Program

The Advanced Technology Program describes itself as "bridging the gap between the research lab and the marketplace."[52] Specifically, the ATP provides cost-shared funding to industry intended to accelerate the development and dissemination of high-risk technologies with the potential for broad-based economic benefits for the U.S. economy. The ATP funding is directed to technical research (but not product development). Companies, either singly or jointly, conceive, propose, and execute all projects, often in collaboration with universities and federal laboratories. The ATP shares the cost for projects that are selected for a limited time. Single-company awardees can receive up to $2 million for R&D activities for up to three years. Larger companies must contribute at least sixty percent of the total project cost. Joint ventures can receive funds for R&D activities for up to five years.

What Does the Program Do?

It Shares Costs to Develop New Technologies with High Risk and High Potential.

Based on peer reviewed competitions, the ATP supports the development of a wide variety of new technologies. These have included adaptive learning systems, component based software, digital data storage, information infrastructure for health care, microelectronics manufacturing infrastructure, manufacturing technology for photonics, motor vehicles and printed wiring boards, new tissue engineering technologies, biopolymer repairs, and tools for DNA diagnostics.[53] These technologies are promising but risky. This means that a significant portion of the ATP-funded projects may fail. Recent research, however, suggests that a significant portion are succeeding.[54] Some projects, such as ATP's early Extreme Ultraviolet Lithography (EUV) research, follow an indirect path requiring some time and substantial additional development to eventually be commercialized.[55]

What Does it Cost?

For the 41 competitions held from 1990-2000, the ATP made 522 awards for approximately $1.640 billion. These awards went to 1,162 participating organizations and an approximately equal number of subcontractors. Universities and non-profit independent research organizations play a significant role as participants in ATP projects. Universities have participated in over half of the projects, involving more than 176 individual universities.[56]

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[52] See the ATP website. http://www.atp.nist.gov/atp/overview.htm (February 2000).

[53] See the paper by Alan P. Balutis and Barbara Lambis, "The ATP Competition Structure" in this volume. See also the paper by Rosalie Ruegg "Taking a Step Back: An Early Results Overview of Fifty ATP Awards" in this volume.

Distinguishing Characteristics

The program has a number of characteristics that collectively distinguish it from other publicly supported technology programs. These include its combination of industry initiative in the identification of technology areas and industry leadership in the planning and implementation of cooperative projects. The selection process is based on both technical and economic merit and is designed to encourage collaboration among companies and with universities and laboratories. To succeed in the selection process, proposals have to have well-articulated technical and economic goals and demonstrate not simply the merit of the work but the specific need for ATP funding. ATP awards are of fixed duration, and involve limited funding. They focus on the development of enabling technologies that have the potential for economic benefits beyond those that can be captured by the innovating firm(s).

Box E. Critical Characteristics of the Advanced Technology Program

Independent researchers have summarized ATP's "critical characteristics" that differentiate it from other government R&D programs as follows:

- a focus on developing the economic benefit of early stage, high-risk, enabling innovative civilian technologies;
- emphasis on the formation of partnerships and consortia;
- rigorous, competitive selection process with an independent evaluation of the project's technical merit, commercial worthiness and potential for broad-based economic benefits; and
- debriefings for those who apply but are not selected.

— Maryann Feldman, Johns Hopkins University

From its modest first-year funding of $10 million, the program grew with the support of a Democratic Congress to more than $60 million in the final years of the Bush Administration. As noted above, the Clinton Administration proposed and initially won substantial increases in ATP funding, but this high-profile sup-

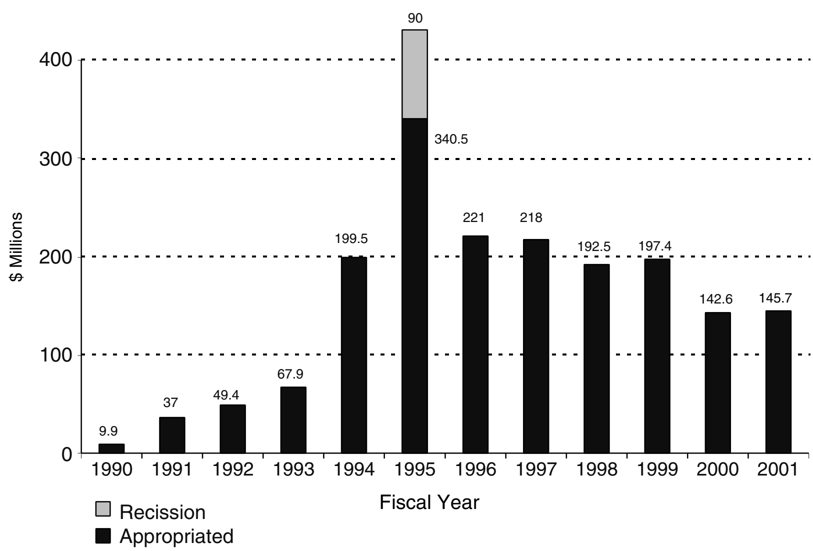
[54] See the paper by Rosalie Ruegg. *Ibid*.

[55] William F. Long, *Advanced Technology Program, op.cit,* pp. 75-77. See also Glenn R. Simpson "Why Chip Firms want U.S. SVG to go to Dutch," *The Wall Street Journal*, New York: Dow Jones and Company, April 26, 2001, B1.

[56] See the paper by Alan P. Balutis and Barbara Lambis, "The ATP Competition Structure" in Chapter V of this volume.

port also generated significant opposition to the program.[57] The political debate about the need for the program, the proper role of government, and the need for government departments such as Commerce and Energy,[58] combined with the pressure for budget deficit reductions, to create what appeared to be a remarkably unstable budget environment. However, as the chart below shows, there was more budgetary stability than the debates of the mid-1990s and the legislative maneuvering in subsequent years might suggest. Essentially, after an initial ramp up in the early years of the Clinton Administration to $340 million, the program stabilized at around $200 million annually with a reduction in FY2000 due in part to the program's inability to fully allocate its funds. Partly as a result of administrative miscalculation, the ATP budget for FY2000 was $143 million, down sharply from $197 million in the previous year. The FY2001 budget saw a return to $191 million (including carryovers from previous years).[59]

Policy Context for Partnerships:
Battles over the ATP Appropriation



[57] As one observer put it, "the irony of White House leadership on this issue has been that what was once a nonpartisan issue in the Congress acquired a partisan undertone. Legislative objectives that received broad support in both parties as recently as the early 1990s can now be cause, at times, for heated debate on the role of the government." Coburn and Berglund, *Partnerships, op. cit.,* p. 484.

[58] See Box G on page 51, on "Picking Winners and Losers."

[59] The total funds available for FY2001were $190.7 million: $145.7 million in appropriated funds and $45 million in carryovers from deobligations. It is important to note that while the appropriation for FY2001 is smaller in total than for FY2000, more funds are available for new awards in FY2001 than in FY2000 ($60.7 million vs. $50.7 million). For FY2002 the initial Administration position was to make no new commitments, but continue to meet existing commitments, pending a re-evaluation of the program.

The difficulty is that this relative stability is most apparent retrospectively. The policy debates and political maneuvering that have characterized the program's annual authorization have been a source of substantial uncertainty. For a research and development program that relies on the formulation of proposals by private firms, often organized in joint ventures, the uncertainty about the availability of ATP funding, either for new programs or for existing commitments, has been a major drawback.[60]

Policy Debate

The controversy with regard to the program during the mid-1990s was related to a broader debate over the role of government in society. In a sense, the debates about the program and the frequent assessments that have resulted may be disproportionate to the scale of the program, particularly in comparison with the SBIR or the mission-specific programs of the Departments of Defense, Energy, and Health and Human Services.[61] To the extent that the debate has generated rigorous assessment of the ATP—as it seems to have—the debate can be seen as a positive addition to the policy dialogue.

To put the policy debate in perspective, two subsections addressing different aspects of the debate are included in this report. To provide background on some of the policy questions examined by the U.S. General Accounting Office (GAO) at the request of congressional committees, a summary of the main points of several of the GAO reports with comments by NIST appears in a shaded box below (Box F). The ATP has also been subject to attack as a program that involves the government picking "winners and losers." This statement contains a number of implicit assumptions that are articulated in Box G below and are examined in relation to the ATP. This information is provided to give an overview of the questions raised about the program. Some of the issues raised have been debated since the very origins of the Republic,[62] a debate that extends well beyond the charge of the authoring committee. As noted above, the Committee's task was to examine the operations and performance of the program in light of its legislated objectives, not to make a fundamental determination about the intrinsic desirability of government-industry-university collaboration.

Some critics have focused their attention on the goals and operations of the ATP itself. One analysis of the program addressed the difficulty of identifying projects with substantial social benefits in excess of private returns.[63] The study

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[60] See the observations by Linda Cohen and Roger Noll cited above and in *The Technology Pork Barrel*, *op. cit.*, p. vii.

[61] See the review of the U.S. General Accounting Office reports in Box F.

[62] See the Preface.

[63] See the paper prepared by Loren Yager and Rachel Schmidt, *The Advanced Technology Program: A Case Study in Federal Technology Policy*, Washington, D.C.: American Enterprise Institute, 1997.

accepts that the economic rationales for the ATP are closely related to traditional arguments for federal support for R&D and notes that the ATP awards might expand the amount of R&D devoted to generic, high-risk technologies. The authors caution, however, that the effectiveness of the ATP depends on whether the program can be successfully implemented. They believe that the ATP is an "interesting experiment in whether the government can promote economic growth through an explicit technology policy."[64] Combining both political and economic perspectives, they argue that "only projects with certain characteristics will enable ATP to achieve its economic goals, and those may not be the same projects that help it to achieve political support."[65] Based on the information available to them in 1995-96, the authors concluded that the program at that time had "had only limited success."[66] In particular, the authors stress the difficulty in identifying and measuring the social returns of ATP projects.[67]

The challenge of identifying and tracking the impact of social benefits has been of interest to economists at least since Alfred Marshall emphasized it in his discussion of the evolution of the modern firm.[68] An analysis of spillovers produced by Adam Jaffe in 1996 distinguished several different mechanisms by which R&D generates spillovers.[69] He identifies "knowledge spillovers," "market spillovers," and "network spillovers" and observes that the three tend to inter-

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[64] For further information on Yager's views, in addition to the GAO reports, see his presentation in National Research Council, *The Advanced Technology Program: Challenges and Opportunities*, *op. cit.*, pp. 42-44.

[65] Yager and Schmidt, *The Advanced Technology Program, op. cit.*, 1997, p. 42.

[66] *Ibid.*

[67] This assessment of the ATP program is based on the authors' review of the ATP project selection criteria as set forth in its legislation, regulations, and administrative notices; no independent economic analysis of the impact of awards was carried out. However, the review is useful insofar as it emphasizes the challenges of assessing, in advance of the award, the prospects for commercial success for a given technology and the potential social benefits. The trajectory followed by a technology is, of course, often unpredictable. The authors themselves note that predicting the likely profits of R&D efforts is enormously difficult, yet they observe that it is much easier than predicting social benefits. *Ibid.,* p. 42. These analytical concerns do represent challenges for the program, and its assessment from an economic perspective. As noted below, the difficulty in assessing counterfactuals necessarily implies some uncertainty about the program's impact. The paper by Maryann Feldman and Maryellen Kelley in this volume does provide recent evidence that the majority of ATP applicants do not undertake their proposed projects in the absence of ATP funding, and, among those that do, the project is normally smaller in scope. This study also suggests that the ATP projects generate benefits beyond those accruing to the individual firm. In addition, ATP awards can impact decisions on private R&D investments. The decision process for R&D investments, particularly in large firms, is often complex; profit maximization is sometimes a guide to firm decision-making in the same sense that the national interest is a guide to decision-making for government agencies.

[68] See Alfred Marshall, *Principles of Economics*, London: Macmillan, 1920.

[69] See Adam B. Jaffe, *Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program,* NIST GCR 97-708, December 1996.

act in a way that increases their combined effect.[70] His analysis highlights the importance for the ATP of seeking projects that have a large spillover gap *and* expected private returns sufficient to make commercialization likely.[71] The ATP selection process seeks to capitalize on this approach. It focuses on multi-use technologies, key components applicable to multiple systems, path-breaking technologies which offer significant economic benefits, and projects which seem likely to generate useful knowledge even if the project itself entails substantial risk. While recognizing the inherent complexity of this type of assessment, Jaffe observes that "the empirical evidence suggests that the average research project generates spillovers."[72] He adds that to the extent the ATP targets projects with better-than-average spillover potential, its awards can generate social returns greater than would otherwise have been achieved.[73]

Box F. GAO Reviews of the ATP

The GAO has reviewed various aspects of the Advanced Technology Program, including issues regarding the award process and elements of its assessment program, at different times. Assessing an R&D program is an inherently complex task, perhaps made more complicated by the program's focus on high-risk technologies with potentially high payoffs. The corollary of high risk is a substantial failure rate. Even venture capital firms, which in principle are focused on opportunities farther down the innovation path, encounter many disappointments in their investments.[74]

[70] *Ibid.,* p. 4. Knowledge spillovers occur when projects generate knowledge that can be used by other parties without compensation, or compensation less than the value of the knowledge. Similarly, market spillovers result when the market for a new product or process causes benefits to flow to parties other than the innovating firm. Network spillovers result when the value of a new technology depends on the development of related technologies (e.g., software applications for use on a new operating system) and widespread use of related technologies.

[71] *Ibid*. In the absence of such returns, projects are unlikely to be commercialized and, hence, less likely to produce significant spillover benefits, although it is also true that some technologies generate spillovers through a more circuitous, indirect path (this process is described by Rosalie Ruegg in her symposium presentation in this volume).

[72] *Ibid.*, p. 21.

[73] *Ibid.*

[74] It is not always appreciated by the general public that even successful venture capital firms normally have many more investment failures than successes. Apparently, a success rate of two out of ten projects can prove acceptable in that one or two substantial successes make good the losses and disappointments of the other eight. This high rate of failure reflects the uncertainty associated with early-stage investing. As Paul Gompers and Josh Lerner point out, venture investors "typically concentrate in industries with a great deal of uncertainty, where the information gaps among entrepreneurs and investors are commonplace." They add that new firms often have substantial intangible

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The venture capitalist's goal is to make good the inevitable losses with the substantial benefits derived from major successes. The ATP's focus on innovative technologies appears to be establishing a similar track record.[75] The challenge for the GAO was to review, usually in a short time frame, the operations of a program involving complex technologies amidst considerable uncertainty as to both technological and market outcomes. An additional challenge is that some of the GAO reports were commissioned relatively early in the program when there were limited results to review because of the normal lead times required for the development of new technologies and processes.

Identification of Similar Research

One of the most recent studies undertaken by the GAO, released in 2000, focused on factors in the ATP selection process that could limit its ability to identify similar research elsewhere.[76] The former chairman of the House Science Committee expressed concern that the program "may have funded research that was similar to research already being funded by the private sector."[77] The GAO reviewed the NIST status report on the first thirty-eight completed ATP projects. The GAO report states in a letter to Representative Sensenbrenner that "as agreed with your offices we determined (1) whether, in the past, ATP had funded projects with research goals that were similar to projects funded by the private sector and (2) if such cases were identified, whether ATP's current award selection process ensures that such research would not be funded in the future."[78] The agency chose three of the thirty-eight completed projects undertaken in 1990 and 1992.[79] Each project represented a different technology sector—biotechnology; electronics; and information, computers and communications. The specific projects focused on areas such as handwriting recognition, regenerating tissues and organs, and capacity expansion of fiber-optic cables.[80]

The GAO found that patents had been issued to others in these general areas and concluded that the three ATP projects addressed similar

assets that are difficult to value and may be impossible to resell. Moreover, the market conditions in many of these industries are often highly variable. Paul Gompers and Josh Lerner, *The Venture Capital Cycle*, Cambridge, MA: The MIT Press, 2000, p. 3.

[75] See Rosalie Ruegg, "Taking a Step Back: An Early Results Overview of Fifty ATP Awards," in this volume, and the earlier assessment by William Long, *Advanced Technology Program*, *op. cit.*

[76] U.S. General Accounting Office, *Advanced Technology Program: Inherent Factors in Selection Process Could Limit Identification of Similar Research*, Washington, D.C.: U.S. General Accounting Office, GAO/RCED-00-114, 2000.

[77] *Ibid*, p. 3.

[78] *Ibid*, p. 4.

[79] *Ibid*.

[80] *Ibid*, p. 7.

research goals to projects in the private sector. The GAO also concluded that the ATP's award process is unlikely to avoid funding similar research, insofar as limits on access to proprietary information and ATP conflict of interest requirements limit the program's ability to identify similar research.[81] The GAO did not, however, recommend any changes to the award selection process. Based on their review of the three projects, the agency stated that "we believe that it may not be possible for the program to ensure that it is consistently not funding existing or planned research that would be conducted in the same time period in the absence of ATP financing assistance."[82]

The Counterfactual Dilemma

This conclusion raises the classic "counterfactual" dilemma of knowing "what would have happened if the award had not been made." Analytically, this is a difficult question to resolve and one which is normally not raised with the same frequency regarding other aspects of federal activity. In its response, NIST disagreed with both the methodology used and the conclusions reached in the GAO assessment. In addition to noting the positive judgments concerning ATP's competitive peer review process, the NIST management argued that this GAO report failed to address a crucial distinction, that is, between projects with similar research goals versus projects with unique objectives and technical approaches in similar fields. NIST noted further that the GAO report contained no reference to the ATP focus on projects with high technical risk, the competitive value of different technical approaches within broad research fields, nor the national benefits that might result from the success of specific projects.[83]

Examining the Award Process

A 1997 GAO review of the ATP involved the provision of information on the ATP award selection process.[84] The GAO describes the ATP as "a competitive, cost-sharing program designed for the federal govern-

[81] *Ibid*, p. 4.

[82] *Ibid*, p. 15.

[83] The NIST director at that time, Ray Kammer, objected to the GAO report, arguing that "the implied argument is that the federal government should not fund research that shares the same overall goal as research funded outside of the government." Kammer argued that by that criterion federal research would be discontinued on cures for diseases such as cancer and AIDS, as well as on wireless communications, computing technologies, and manufacturing. See *New Technology Week*, Monday, May 1, 2000, p. 3.

[84] U.S. General Accounting Office, *Federal Research: Information on the Advanced Technology Program's 1997 Award Selection: Statement of Susan D. Kladiva before the Subcommittee on Technology, Committee on Science, U.S. House of Representatives*, Washington, D.C.: U.S. General Accounting Office, GAO/T-RCED-98-92, 1998.

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ment to work in partnership with industry to foster the development and broad dissemination of challenging, high risk technologies that offer the potential for significant, broad-based economic benefits for the nation." The GAO's inquiry focused on whether ATP applicants could obtain funding elsewhere, and whether not funding a project "would create a serious national economic concern." The report states that the ATP rejects project proposals when it concluded that (1) the applicants could probably find funding elsewhere, or (2) a delay in project progress would not be a serious national economic concern. The GAO's analysis focused on the information that the ATP used to make these determinations.

Selection Criteria

The GAO noted that the ATP selects projects for funding based on five selection criteria, which are used by peer reviewers in the assessment of proposals.[85] These criteria are

- scientific and technical merit;
- potential net broad-based economic benefits;
- adequacy of plans for eventual commercialization;
- level of commitment and organizational structure; and
- experience and qualifications.

With respect to the availability of private funds, the ATP review process includes requests for information concerning efforts to obtain funding and also provides opportunities to question the applicants on this point during the oral review phase. In addition, the GAO reports that the ATP now requests additional information on company efforts to obtain outside funding as part of the overall decision on the applicant's proposal. With respect to the second question regarding topics of national economic concern, reviewers were asked to evaluate the proposed project in terms of its potential to improve U.S. economic growth and productivity, timeliness, the degree to which ATP funding is necessary, and cost-effectiveness.

Progress without ATP?

A 1996 GAO assessment sought to determine whether research projects would have been funded by the private sector if they had not received funds from ATP—again the "counterfactual" question.[86] The GAO

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[85] The GAO noted that the 1997 focused program competitions addressed motor vehicle manufacturing technology, information infrastructure for health care, component-based software, and tissue engineering.

[86] U.S. General Accounting Office, *Measuring Performance: The Advanced Technology Program and Private-Sector Funding*, Washington, D.C.: U.S. General Accounting Office, GAO/RCED-96-47, 1996.

found that half of the near-winners continued their projects without relying on ATP funding, albeit at reduced levels of activity, while the other half discontinued their projects.[87] The GAO also examined the ATP's impact on other goals such as aiding the formation of joint ventures. The survey found that more than three-fourths of the joint venture applicants had come together to pursue an ATP project, thus satisfying ATP's goal of serving as a catalyst for the formation of joint ventures[88]—such arrangements tend to encourage the diffusion of research results, a related ATP goal.[89] The report suggests there may be some overlap with private funding.[90] At the same time, the GAO report also concludes that ATP awards encourage the formation of joint ventures and help companies achieve research milestones faster.

In response, the ATP argued that the GAO findings support the view that ATP is accelerating technology development insofar as the near-winners normally do not proceed at the same pace and scale of activity in the absence of the ATP award.[91]

Early Evaluation

A 1995 GAO assessment focused on NIST's efforts to evaluate the Advanced Technology Program. At the outset, the GAO report notes that "Evaluating ATP poses many challenges. For example, ATP research projects are intended not only to be technical successes but also to have commercial results. The linkage between technical work and commercial results may not always be direct, and may be subject to interpretation. Also, several years can elapse between the end of technical work and the realization of commercial results." A key GAO conclusion was that it was too early (in 1995) to determine the ATP's long-term economic impact.

In describing NIST's extensive assessment efforts, the report was critical of the program's initial effort to assess the short-term results of its

[87] NIST argues that companies may reduce the scope, scale, and nature of the research goals, with the result that under the same project description, a much smaller-sized effort is under way at a slower pace. *Ibid.,* p. 2.

[88] *Ibid.*

[89] This view was subsequently reinforced by the findings outlined in the Feldman and Kelley paper, "Leveraging Research and Development: The Impact of the Advanced Technology Program," in this volume. The authors found that firms selected by the ATP were more likely to share the research findings, thus contributing to their dissemination.

[90] Feldman and Kelley find that the receipt of an ATP award has a "halo effect" in that it "significantly increases the firm's success in attracting additional funds from other sources for R&D activities," *Ibid*., p. 12.

[91] The more recent Feldman and Kelley study finds that 62 percent of the non-winners had not proceeded with any aspect of the R&D proposed to the ATP. More than a third did undertake the proposed work, but in more than three-quarters of these cases, the project was pursued on a smaller scale. *Ibid*.

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awards, describing them as overstated.[92] The same report noted NIST's efforts to extend its evaluation by engaging the advice and services of the nation's leading economists in impact assessment and evaluation, conducting microeconomic case studies, supporting the use and development of economic models, and establishing an extensive data collection system.[93]

These necessarily abbreviated reviews of the almost annual GAO reports demonstrate the range of questions that can be asked about programs to support the development of new technologies as well as the difficulty of a definitive response.[94] As noted above, the GAO analysts themselves underscore the challenge of evaluation and note that the ATP assessment program is itself seeking to answer similar questions. The GAO reports provide a valuable perspective on various aspects of the ATP. At the same time, it should be kept in mind that the GAO reports are necessarily constrained by the questions they are asked to address and are normally limited in the scope of their analysis. They provide an additional outside source of assessment that has encouraged and is complementary to the assessment process developed by the ATP.

As the survey of the GAO reports on the ATP suggests, assessment of government R&D programs is as desirable as it is difficult. However, some observers and participants object to a role for the federal government in the support of technology development beyond basic research on the grounds that it is unable to do so effectively. Others would accept a federal role for technology development that is limited to specific national missions. Because these views are often raised with respect to the Advanced Technology Program, the box below discusses this perspective in the context of current federal technology policy and particularly in relationship to the ATP.

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[92] U.S. General Accounting Office, *Performance Measurement: Efforts to Evaluate the Advanced Technology Program,* Washington, D.C.: U.S. General Accounting Office, GAO/RCED-95-68, 1995. In its response, NIST objected to the GAO findings criticizing the GAO for misrepresenting NIST statements with regard to the short-term impact of ATP and its then-nascent evaluation program. NIST defended its evaluation plan as appropriate, informative, and well-founded. See pp. 14-27.

[93] *Ibid.,* p. 8. NIST contracted with the National Bureau of Economic Research for part of its assessment activity.

[94] The difficulty of arriving at a definitive response is not confined to the GAO reports nor the internal ATP assessments. An excellent, comprehensive survey by Paul David, Bronwyn Hall, and Andrew Toole notes, "the paucity of systematic statistical evidence documenting a direct contribution from public R&D" while also noting that "there is a significantly positive and relatively high rate of return to R&D investments at both the private and social level." *Is Public R&D a Complement or a Substitute for Private R&D? A Review of the Econometric Evidence*, NBER Working Paper No. 7373 (October 1999), p. 2.

Box G. "Picking Winners and Losers" and the Advanced Technology Program

In the United States, discussions of best practice concerning partnerships between the government, industry, and universities often include statements to the effect that the government cannot—or should not—"pick winners or losers." For example, a recent GAO study described two views of the ATP, as follows: "Thus, ATP is seen by some as a means of addressing market failure in research areas that would otherwise not be funded, thereby facilitating the economic growth that comes from the commercialization and use of new technologies in the private sector. Advocates of the program believe that the government should serve as a catalyst for companies to cooperate and undertake important new work that would not have been possible in the same time period without federal participation. Critics of the program view ATP as industrial policy, or the means by which government rather than the marketplace picks winners and losers."[95] By this expression "picking winners and losers," it is generally meant that

a. the government does not have the capability to make judgments concerning new technologies or firms;
b. the government should not substitute its judgment for that of the market by selecting among technologies or firms;
c. government intervention in the market is unwarranted and constitutes a form of corporate welfare.[96]

These arguments are obviously interrelated, and their appeal is grounded in the popular perception of an American economy regularly transformed by individual investors and entrepreneurs. This view is, of course, well founded, both in terms of American economic history and today's economy. Yet it is equally true that the federal government has long played a nurturing role, with the result that in many cases the process of innovation in the U.S. economy is the result of a complex

[95] U.S. General Accounting Office, *Advanced Technology Program: Inherent Factors in Selection Process Could Limit Identification of Similar Research*, *op. cit*., p. 5.

[96] See, for example, the testimony by Dr. Edward L. Hudgins, before the Senate Committee on Commerce, Science and Transportation, 1 August 1995. In addition to recommending the abolishment of the Department of Commerce and NIST, Hudgins argues that "In the area of advanced commercial technologies, that is, the high-tech revolution of the past 15 years, the private sector already does a world-class job in developing new products and technologies. Thus, ATP is unnecessary. The way a market system—as opposed to a corporatist or socialist system—works is that if there is a prospect for a profit, entrepreneurs will risk investing in order to reap profits. For example, the cost of bringing a new pharmaceutical product to market is now on average $390 million. Yet drug companies make such investments. If there is a profit to be made, entrepreneurs will act with or without government handouts."

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interaction of public and private initiative. Arguments that do not take this interaction into account ignore important parts of the history of technology development in the United States. They also do not reflect recent and current practice with respect to the development of new technologies.[97] This is especially true with respect to platform technologies such as the Internet, or contributions to enabling technologies such as semiconductors, or the sustained research and development support of the National Institutes of Health to the pharmaceutical, medical device, and biomedical industries.[98]

Judgments

The government has demonstrated a capacity to make judgments with respect to new technologies. It has been instrumental in developing major new industries through a variety of means, including awards for demonstration projects, provision of long-term R&D support (e.g., the National Advisory Committee for Aeronautics [NACA]),[99] support of a regulatory framework, and provision of early assured markets through government procurement. Major government initiatives for exploration and defense (e.g., the Apollo and Minuteman programs) provided generous "cost-plus" procurement contracts that made a major contribution to the growth of Silicon Valley.[100] One recent analysis argues that "In effect, the U.S. defense policy after WW II was an innovation policy, which greatly benefited Silicon Valley's high technology firms by creating price-insensitive lead customers and by funding pre-commercial research, supporting universities, and training engineers and scientists."[101]

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[97] See the Preface and the Introduction for a brief overview of the historical and policy context in which the ATP was developed.

[98] Public grants to non-profits and private companies constitute a significant portion of NIH funding. In FY2000, $1.0 billion, or nearly 7 percent, of NIH funding for research grants and R&D contracts went to for-profit organizations. An additional $1.4 billion, or 10 percent, went to non-profit institutes, some of which are reported to be closely associated with for-profit firms. For NIH funding by performer in FY2000, see: http://silk.nih.gov/public/cbz2zoz.@www.trends00.fy9100.per.htm. For increasing relationships between nonprofit research institutions and for-profit firms, see Chris Adams, "Laboratory Hybrids: How Adroit Scientists Aid Biotech Companies with Taxpayer Money—NIH Grants Go to Nonprofits Tied to For-profit Firms Set up by Researchers," *Wall Street Journal*, New York: Dow Jones and Company, January 30, 2001, p. A1.

[99] Founded in 1915, NACA made major contributions to aeronautics, as noted above, until it was incorporated into NASA in 1958.

[100] A recent analysis of the factors contributing to the development of Silicon Valley emphasized the role of defense spending in the Valley's development. See the articles by Timothy J. Sturgeon, "How Silicon Valley Came to Be," and by Stuart A. Leslie, "The Biggest 'Angel' of Them All: The Military and the Making of Silicon Valley," in Martin Kenney, ed., *Understanding Silicon Valley: The Anatomy of an Entrepreneurial Region*, Stanford, CA: Stanford University Press, 2000.

[101] Martin Kenney, *Understanding Silicon Valley, op. cit.,* p. 5.

Academic critics of some government-supported technology programs record both successes and failures in government efforts to support new technologies through these multiple mechanisms. One well-known assessment of the major commercialization demonstration projects of the 1970s observed that there are frequent failures as well as successes among federal R&D programs and counted among the successes telegraphy, hybrid seeds, aircraft, radio, radar, computers, semiconductors, and communication satellites.[102] In short, amidst both failure and success, government support for new technologies has laid much of the foundation for the modern economy. As a recent National Academies study noted, "The development of the Internet demonstrates that federal support for research, applied at the right place and the right time, can be extremely effective."[103] Of course, a great advantage of the American system is that, after government actions have contributed to a technological advance, the development of the technology and its commercialization are left in the hands of multiple players in the private sector.[104] The ATP's broad mandate to support risky but promising technologies that may contribute to new products and processes, enhance U.S. competitiveness, or accelerate welfare-enhancing technologies (e.g., improved mammography) is more controversial than, say, DOD funding of computing and networking development, because the program is not tied to a specific mission or constituency.

Intervention

One of the great strengths of the U.S. economy is that the government sees its central role as an arbiter of economic competition among private actors. To a remarkable degree, this is accurate, yet the fact remains that the government does intervene in the market in many ways, be it through the provision of R&D support, development of a favorable regulatory framework, or procurement decisions for technologies for gov-

[102] See Linda R. Cohen and Roger G. Noll, *The Technology Pork Barrel, op. cit*., p. 3. More recently, the Office of Science and Technology Policy took a similar view, noting that federal funding of research and development has led to such advances as atomic energy, the Internet, the Global Positioning System, lasers, solar-electric cells, storm windows, Teflon, communications satellites, jet aircraft, microwave ovens, genetic medicine, and a wide array of advanced materials and composites. Office of Science and Technology Policy, *Fact Sheet on How Federal R&D Investments Drive the U.S. Economy*, Executive Office of the President, June 15, 2000, http://www-es.ucsd.edu/stpp/whouse(rp).htm#06153.doc.

[103] See National Research Council, *Funding a Revolution, op. cit.,* p. 181. The federal government has played a critical role in supporting the research that underlies computer-based products and services. Federal funding rose from less than $10 million in 1960 to almost $1 billion in 1995. The vast majority of the funding has been awarded to industry and university researchers. *Ibid.,* pp. 2-3. See also Michael Hauben and Ronda Hauben, *Netizens: On the History and Impact of Usenet and the Internet*, 1998, http://www.columbia.edu/~rh120/.

[104] Irwin Lebow, *Information Highways and Byways, op. cit.*, pp. 9-12.

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ernment missions ranging from defense, space exploration, and health. The government role, of course, is not confined to investment incentives. Its role in infrastructure building, support for research—both early and applied—and for training are all integral parts of the government's support for economic growth. Although not without controversy, the exercise of government's regulatory responsibilities has played a key role in the computing and telecommunications industries. For example, anti-trust actions in the 1950s were intended to facilitate the entry of other companies and more rapid innovation in the computer industry.[105] In recent years, since the Telecommunications Act of 1996, government and industry have been closely involved in an ongoing debate concerning the optimal regulatory regime.[106] In short, the government has demonstrated the capability to make judgments concerning new technologies but also must make such decisions to carry out its various responsibilities.[107]

Private-Sector Lead

Federal support for advanced technologies has involved many mechanisms. As noted above, until the mid-1980s, federal support normally took the form of research grants or contracts for product development or procurement programs that often had a significant research component. After 1985, a number of programs were established that involved partnerships among government, industry, and universities. These programs included the Semiconductor Research Corporation, the NSF Engineering Research Centers, SEMATECH, Cooperative Research and Development Agreements (CRADAs), the Manufacturing Extension Partnership Program, and the Advanced Technology Program.[108] Unlike many

[105] National Research Council, *Funding a Revolution*, *op. cit.*, p. 33.

[106] Since the Telecommunications Act of 1996, P.L. No. 104-104, 110 Stat. 56 (1996), the stakes for firms with incumbent positions and start-ups with different technologies and business plans have been enormous. Some are seeking new spectrum allocation (or re-allocation), others regulatory support through active enforcement of the act. The government's role is a critical component in the competitive position of many firms.

[107] As with the private sector, the government's judgment and capability do not insulate it from failure. Both the private sector and the government face the same uncertainties. Each must place bets, albeit for different reasons. Each cannot avoid the certainty of losers. Each can cover enough points to be assured of some winners. "In short, winners and losers are an inevitable by-product of the process of innovation. Picking winners and losers is the wrong metaphor to characterize the socially useful and necessary activity of government in supporting that process. Government is actually placing bets on our collective future, and from the public standpoint, the magnitude of the potential social gains are sufficiently large to provide a comfortable margin for error in choosing among technologies to back." See the testimony of Professor Michael Borrus, University of California at Berkeley, before the House of Representatives Committee on Science, Subcommittee on Technology, April 10, 1997. http://www.house.gov/science/borrus_4-10.html.

[108] National Research Council, *Funding a Revolution, op. cit.,* pp. 32-33.

cooperative programs, the ATP relies on the private sector to identify promising areas of technology, such as biomedical devices, information technologies and materials, and communications (e.g., optoelectronics) and to design, lead, and manage the projects. The ATP's reliance on peer review by both industry business experts and government technical experts ensures, to the extent possible, the technical quality of proposals and a potential for economic impact.[109] The requirement of a plan for commercialization encourages, but cannot ensure, a pathway to commercial development. Rather, the commercialization plan requirement is designed to ensure that projects that cannot offer at least a potential pathway to development are not supported with public funds.[110]

"Reality Checks"

To avoid open-ended commitments of public funds to uncertain technologies, the ATP has incorporated features that serve as "reality checks," most notably, the matching expenditure of private funds by for-profit firms. This cost-share requirement, the limited financial commitment of the government through one-time awards, and the limited duration of the awards protect ATP against the frequently justified criticism of open-ended government-led technology commercialization programs that characterized the major government initiatives of the 1970s and early 1980s.[111] Compared with these 1970s programs, ATP is a much smaller, more limited, and more focused effort with different mechanisms (e.g., one-time, competitive awards) focused on R&D more likely to diffuse across the economy.[112] Its encouragement of company-university-laboratory collaboration and coordination with other public and private efforts is another distinguishing characteristic.[113]

Perhaps most important is the ATP's support for innovation that is expected to generate significant spillovers yielding broad national economic

[109] Some critics of the program argue that the government cannot pick winners, that is, substitute the judgment of bureaucrats for decisions properly made by the market. Other critics argue that the ATP's selection of projects based on input from industry is equally suspect, leading "to the conclusion—certainly the suspicion—that the real reason for individual sector selection was to reap political support from successive groups of corporate leaders. . ." who would provide pressure against future program cuts. Claude E. Barfield, testimony before the Subcommittee on Technology of the House Science Committee, April 10, 1997.

[110] For an overview of the ATP selection process, see the analysis by Alan P. Balutis and Barbara Lambis, "The ATP Competition Structure," in this volume. For an assessment of the impact of the program, see the analysis by Maryann P. Feldman and Maryellen R. Kelley, "Leveraging Research and Development: The Impact of the Advanced Technology Program," in this volume.

[111] See Linda R. Cohen and Roger G. Noll, *The Technology Pork Barrel, op. cit.*

[112] Feldman and Kelley, "Leveraging Research and Development," in this volume find that projects and firms selected by the ATP are more willing to share their research findings and tend to be firms that open new paths of innovation by drawing on multiple technical areas through R&D partnerships.

[113] *Ibid*. Universities play a significant role in many ATP projects.

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benefits. This approach constitutes an important source of risk for the program.[114] The ATP's interest in enabling technologies with high spillover potential that are also subject to substantial technical challenge means it is also a source of substantial potential benefit for the economy. By definition, the high-risk, high-payoff strategy means that many ATP projects will not achieve success.[115] The program deliberately seeks projects needing the catalytic effect of a government award to bring together the university-industry partners to achieve technological advances.[116]

The Policy Context

Lastly, the program has to be considered in context. The ATP is one element of a national innovation system that employs a variety of policies and instruments to encourage the discovery, development, and exploitation of new technologies.[117] It is not a panacea for the challenges facing the U.S. economy. It is a program that the research outlined here suggests is achieving its goals with a degree of success commensurate with the technical and commercial difficulties associated with the program's objectives. It holds the potential of advancing commercially and perhaps socially valuable technologies. It is a program that might be improved, and this report recommends some ways to do so. Whatever improvements might be made in the program, the dialogue about such programs certainly can be improved, not least by careful research, regular assessment, and attention to the initiatives under way around the world. A constructive dialogue about measures to capitalize on the substantial and growing U.S. R&D investment in areas of great promise needs to be advanced both to avoid misallocation of public funds and to capture the substantial benefits of new technologies for the American economy.

The Need for Assessment

As reflected in the reviews and debates summarized above, one consequence of the debates about government-industry partnerships in general, and the ATP in particular, has been a desire for objective analysis of the goals, operation, and

[114] Lewis Branscomb and Philip Auerswald, *Taking Technical Risks: How Innovators, Managers, and Investors Manage Risk in High-Tech Innovation*, Cambridge, MA: MIT Press, p. 145.

[115] ATP successes, insofar as they can be judged, are about 16 percent of the program—a rate comparable to venture capital programs which normally operate later in the development cycle. For an overview of the ATP record, see the analysis by Rosalie Ruegg, "Taking a Step Back: An Early Results Overview of Fifty ATP Awards," in this volume.

[116] See the paper by Jeffrey Dyer and Benjamin Powell, "Perspectives on the Determinants of Success in ATP-sponsored R&D Joint Ventures: The Views of Participants," in this volume and the summary of their findings in Section B on page 60.

[117] See Richard R. Nelson, editor, *National Innovation System: A Comparative Study*, New York: Oxford University Press, 1993.

results of partnership programs. This pragmatic approach with regard to assessment was captured in a 1995 RAND study, which observed that:

> The federal government has undergone a sea change the past few years in its approach to the private sector. The broad awareness of and support for these activities in Congress and their spread throughout the $80 billion federal R&D system ensure that they will continue well into the next Administration and beyond. The debate should address not whether these programs will endure, but whether they are shaped properly—at the program and aggregate levels—to achieve the desired benefits.[118]

Reflecting this perception, the Senate requested that NIST commission an outside review of the operations of the Advanced Technology Program.[119]

The National Research Council Analysis: Report Structure

To carry out this review, the National Academies undertook an analysis of the ATP under the terms of reference of its study of *Government-Industry Partnerships for the Development of New Technologies*. As described in the Preface, this project is being carried out by a distinguished Steering Committee under the National Research Council's Board on Science, Technology, and Economic Policy. The study is to contribute to improved understanding of partnerships through commissioned research, conferences, and workshops bringing together policy makers, program managers, academic experts, technologists, and representatives of industry.

As noted above, this volume is the second report in this series on the Advanced Technology Program[120] and is designed to further our understanding of the operations and impact of this program. This report has five main parts. The Preface is intended to give an overview of the overall project and fix the ATP assessment within the context of this broader analysis. The Introduction gives an overview of federal technology policy, fixing the ATP in the context of U.S. efforts to develop new technologies through various forms of government incen-

[118] Coburn and Berglund, *Partnerships, op. cit.*, p. 487.

[119] In Senate Report 105-235, the Advanced Technology Program was directed to arrange for a well-regarded organization with significant business and economic experience to conduct a comprehensive assessment of the ATP, analyzing how well the program has performed against the goals established in its authorizing statute, the Omnibus Trade and Competitiveness Act of 1988.

[120] See the Preface. Six reports on various aspects of partnerships have been published; two others are in preparation. The first report was National Research Council, *The Advanced Technology Program: Challenges and Opportunities,* Charles W. Wessner, editor, Washington, D.C.: National Academy Press, 1999.

tives, support, and cooperation. To facilitate the reader's task, the Introduction also includes a summary of the seven papers prepared for the volume and of the symposium deliberations.

Chapter III provides the Committee Findings and Recommendations for assessing the operation of the program and making recommendations for its improvement. Chapter IV provides a detailed summary of the presentations of the one-day symposium, entitled "Assessing the Advanced Technology Program: Issues and Outcomes," held April 25, 2000. The symposium brought together policy analysts, economists, Department of Commerce officials responsible for the ATP, and representatives of private industry to review the ATP's objectives, describe its selection process, and review case studies from the assessment program, as well as discuss the ATP's rationale, program strengths and weaknesses, and consider potential areas for improvement. The summary of the deliberations in Chapter IV are complemented by seven papers that describe the evolution and nature of the ATP competition process and assess, from a variety of perspectives, the impact of the ATP awards. The symposium summary and the related case studies represent the second phase of an analysis requested by NIST in response to a congressional mandate to provide an independent review of ATP program operations.

Section B below provides an overview of the papers collected for this volume. They illustrate the scope, quality, and challenges of the assessment effort while providing insights into the operation of the program. The following section provides a summary of the main points of the workshop proceedings.

B. OVERVIEW OF THE PAPERS

Studies from the Assessment Program

A variety of evaluation methods, both qualitative and quantitative, are now being used to assess the effectiveness of ATP awards. The papers collected here are drawn from a growing body of studies focused on the ATP contribution and awardee performance. These studies have focused on a range of issues such as the ATP's effect on the innovation process, the commercial progress of the innovators, various spillover effects, and combinations of these effects, while others seek to improve the tools of evaluation needed to measure performance. Many of these studies are quite extensive (e.g., the study of the printed wiring board consortium).[121] In these cases, summary versions of the studies were prepared to illustrate the methodology and summarize the main points.

Assessing the ATP Contribution

The first paper, led by Professor Maryann Feldman of Johns Hopkins University, is particularly important in that it focuses on the ATP contribution to private-sector innovation. Using data from a survey of 1998 ATP applicants, the study finds that most of the non-winners did not proceed with any aspect of their proposed R&D project, and, of those that did, most did so on a smaller scale than initially proposed. This suggests that ATP funding is not simply displacing private capital.

Importantly, the program received high marks from its users. A substantial majority of the applicants surveyed by Feldman and Kelley widely considered ATP's application process to be fair and rational. Further, the survey finds that the projects and firms selected by ATP are more willing than those not selected to share their research findings with other firms and tend to be collaborative in new technical areas and form new R&D partnerships—findings consistent with ATP's goal of selecting projects with large spillover potential. The study also finds that the ATP award can create a "halo effect" for recipients, increasing the success of award recipients in attracting additional funding from other sources, an effect documented by several earlier researchers.[122] Feldman and Kelley conclude that

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[121] A. N. Link, *ATP Early Stage Impacts of the Printed Wiring Board Research Joint Venture, Assessed at Project End*, NIST GCR 97-722, November 1997.

[122] See Silber & Associates, *Survey of Advanced Technology Program 1990-1992 Awardees: Company Opinion about the ATP and its Early Effects*, NIST GCR 97-707, February 1996; and Solomon Associates, *Advanced Technology Program: An Assessment of Short-Term Impacts—First Competition Participants*, February 1993. See also J. Lerner, "'Public Venture Capital': Rationales and Evaluation," in National Research Council, *The Small Business Innovation Research Program: Challenges and Opportunities*, Charles W. Wessner, editor, Washington, D.C.: National Academy Press, 1999, pp. 115-128.

the ATP is leveraging activities that have the potential to contribute to broad-based economic growth.

Accelerating Collaborative Activity

The architects of the ATP apparently anticipated the growing importance of collaborative activity to national technological prowess, and made the fostering of collaboration a prominent feature of the ATP. Some of the ATP evaluations therefore focus on the collaborative aspect of ATP awards. Professor Jeffrey Dyer of the Wharton School and, more recently, Brigham Young University, identifies factors that increase or decrease the likelihood of collaborative success from the perspective of participants in ATP-funded joint ventures in the automotive industry. His findings suggest that

- the ATP is accelerating and improving the successful outcome of collaborative projects;
- the ATP projects are taking on higher risk and longer-term research than collaborative endeavors without government involvement; and
- the ATP is providing funding during critical stages, overcoming barriers to collaborating, increasing project stability, and causing collaborative projects to run more smoothly, albeit with some perceived loss of flexibility on the part of participants.

Case Studies

Several papers are case studies designed to measure various elements of performance of specific projects or collections of projects.

Wiring Boards

The earliest of these, by Professor Albert Link of the University of North Carolina-Greensboro, also addresses the value of collaboration. He focuses on the impact of an ATP-funded joint venture on the costs and timing of developing a suite of "leap-frog" technologies for the U.S. printed wiring board industry. Link finds major R&D efficiency gains from the project, estimating the resulting cost savings in the millions of dollars. He also finds that the competitive positions of U.S. producers improved substantially and attributes this to their strengthened technical capabilities. The resulting employment effects are reportedly positive and substantial.[123]

[123] The head of the National Center for Manufacturing Sciences declared that the project was instrumental in turning around the declining wire board industry, contributing to the retention of approximately 200,000 jobs.

Medical Technology: Tissue Engineering

The study by researchers at the Research Triangle Institute's (RTI) Center for Economic Research develops an evaluation framework for assessing medical technologies to apply to seven ATP-funded tissue-engineering projects. These projects offer new medical treatments, mostly at lower costs. RTI computes three measures of benefit for each project: (1) social return on investment; (2) private return on investment; and (3) social return on public investment, or the return on ATP's investment based on the difference in social return with and without the ATP. They compute a composite social return across the seven projects in the billions of dollars (net present value). They conclude that expected social returns are much larger than private returns, primarily due to projected positive spillovers to patients treated with the new technologies. Also, they conclude that the ATP played a significant role in increasing expected returns on these projects by accelerating the R&D phase of the projects and improving the probability of technical success.

An Economic Model

In the fifth study, a more theoretical approach is taken by two economists at Resources for the Future, David Austin and Molly Macauley. This paper projects potential gains from ATP-supported technologies and in addition illustrates the contributions the ATP's evaluation program has made to the increasingly important field of technology impact assessment. The ATP has engaged leading economists and other evaluators to apply state-of-the-art evaluation techniques to assess the impact of the program. In doing this, it has also commissioned work that extends the state of the art of evaluating new technologies by testing new methods on ATP-funded projects. The work by Austin and Macauley may represent an advance in evaluation modeling capability, as well as adding to our knowledge of the potential impact of two ATP-funded projects in digital data storage. This study estimates that each of these projects, if successfully commercialized, would generate consumer benefits in excess of a billion dollars. It is important to note that the findings are dependent on successful commercialization of the technologies, which is not assured.

Aggregate Analysis

The final paper, prepared by Rosalie Ruegg, provides an aggregate analysis of the first fifty completed ATP projects drawn from small case studies compiled by a number of analysts. This overview describes the results of a substantial group of ATP-funded projects, several years after completion. The fifty projects are rated in terms of the creation of new technical knowledge, dissemination of new knowledge to others, and direct use of the new knowledge by the innovators to accelerate commercial use of the technology—three dimensions of performance that figure prominently in the long-run success of the ATP. As one would expect for high-risk R&D, many of the projects are rated as weak performers (26 percent); most of the projects (58 percent) fall somewhere in the middle. Yet expected net benefits from the strong performers (16 percent) are more than enough to yield a robust performance for the group of fifty taken as a whole. In the aggregate, the expected benefits of stronger performers would outweigh total program costs to date. Strictly speaking, this level of return is not the goal of the ATP. It does provide one measure of return on investment.

Conclusions and Caveats

These studies, performed by different researchers using different approaches, are generally positive in their findings, although the complexity and tentative nature of the more recent assessments must be kept in mind. Technologies now showing progress may nevertheless fail to deliver expected benefits. Individually and collectively, the analyses suggest that the ATP is making progress toward achieving its intended mission. In addition, the program's sustained evaluation effort is developing valuable tools for the assessment of U.S. technology policies.

C. SUMMARY OF SYMPOSIUM PROCEEDINGS

The text below provides a summary of the major statements by participants in the symposium.

Introduction to the Symposium

Clark McFadden, a partner in the Washington law firm Dewey Ballantine, opened the symposium with a review of the policy issues facing the ATP. Mr. McFadden, who has broad experience in the creation of government-industry partnerships, is a member of the Steering Committee assembled by the STEP Board to carry out its program-based review of government-industry partnerships. He noted that this fact-finding meeting is one in a series of reviews organized under the auspices of the NRC program on *Government-Industry Partnerships for the Development of New Technologies*.

The ATP, he said, is unique among government research and technology programs in several respects:

- The program's goals go beyond basic research (or specific mission goals) to supporting industrial research in "enabling" technologies and encouraging commercialization of those technologies. It is therefore on the leading edge of government-industry relationships.
- The program has been intensively studied and assessed. The core competence of the National Institute of Standards and Technology, ATP's parent, is measurement, and the agency has assiduously assessed the outcomes of the program.[124] The Steering Committee, for its part, has been able to draw on the extensive assessment effort that NIST has commissioned in cooperation with economists of the independent National Bureau of Economic Research (NBER) and other researchers. The Committee's goal is to bring varied points of view to bear on the program's effectiveness, efficiency, and rationale.[125] These reviews have helped the Steering Com-

[124] Several recent examples are included in this volume, such as D. Austin and M. Macauley, *Estimating Future Consumer Benefits from ATP-funded Innovation: The Case of Digital Data Storage*, NIST GCR 00-790, April 2000 (see Chapter V of this volume). The ATP assessments also include a report by William F. Long providing a comprehensive, qualitative review of the outcomes of ATP investments, documenting research accomplishments, subsequent work by companies to commercialize the results, and near-term outlooks for the successful companies. This rich summary is exceptional in that it also documents ATP projects that were terminated in the same period, with brief explanations. William F. Long, *Advanced Technology Program: Performance of Completed Projects—Status Report Number 1, op. cit.* Rosalie Ruegg provides an updated overview of progress on fifty awards in Chapter V of this volume.

[125] In addition to NIST's own research, the U.S. General Accounting Office and congressional committees have shone their own spotlights on the program. The findings of several of these reports are summarized above. For the complete reports, see U.S. General Accounting Office, *Advanced*

mittee develop better ways to balance the risks, returns, and opportunity costs of other government-industry collaborations.

The Steering Committee, McFadden added, has already produced one publicly available report on the ATP, describing its goals, assessment program, and providing comments from critics, supporters, and participants in the program.[126] The focus of today's meeting, he said, is to assess the program's results and its effort at evaluation.

The ATP Objective: Addressing the Financing Gap for Enabling Technologies

Committee member Charlie Trimble, of Trimble Navigation, introduced the first panel by reminding participants that the ATP was originally established to address the "funding gap" for emerging technologies (that is, the tendency of the private sector to underinvest in early-phase research and development). This session would attempt to understand the behavior of private investors and their perspective on the ATP, through the prism of three panelists, from widely different worlds:

- the proprietor of a start-up company that has received ATP funds;
- a successful venture capitalist; and
- a representative of a global technology firm that participates in the program.

A Start-up's Perspective

Elizabeth Downing—President and CEO of a Palo Alto high-technology start-up company—reviewed the experience of her firm, which had received a single-company ATP grant about one and one-half years earlier to develop a new concept in imaging known as Crossed-Beam Displays. Addressing a fundamental question about the ATP, she asked, "Why should government fund the development of enabling technologies? Because enabling technologies have the potential to bring enormous benefits to society as a whole. Yet private investors will not

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Technology: Proposal Review Process and Treatment of Foreign-Owned Businesses, RCED-94-81, Washington, D.C.: U.S. Government Printing Office, 1994; U.S. General Accounting Office, *Performance Measurement: Efforts to Evaluate the Advanced Technology Program, op. cit.*; U.S. General Accounting Office, *Measuring Performance: The Advanced Technology Program and Private-Sector Funding, op. cit.*; U.S. General Accounting Office, *Federal Research: Information on the Advanced Technology Program's 1997 Award Selection, op. cit.*; U.S. General Accounting Office, *Advanced Technology Program: Inherent Factors in Selection Process Could Limit Identification of Similar Research, op. cit.*

[126] National Research Council, *The Advanced Technology Program: Challenges and Opportunities. op. cit.*

adequately support the development of these technologies, because profits are too uncertain or too distant."

Enabling technologies, she said, are technologies that show the potential to make radical improvements in some aspect of society or even create new industries. However, they tend to be disruptive—by displacing entrenched industries. Fundamentally, they are too immature and risky to interest private investors, which is understandable, because they may require years or decades to become commercially viable and generate profits.[127]

Another unusual feature of her company's experience is that it has received several different types of federal awards. These include SBIR grants, DARPA contracts, and Cooperative Research and Development Agreements with universities. Of all the federal funding programs that her young company has participated in, she said, the ATP was by far the most useful because of its large funding commitment, long time duration, and administrative simplicity. It allows the technical and market risks of the technology to be reduced, while keeping control of the technology in the hands of the company itself.

Box H. Why Should Government Fund Promising Technologies?

"Why should government fund the development of enabling technologies? Because enabling technologies have the potential to bring enormous benefits to society as a whole. Yet private investors will not adequately support the development of these technologies, because profits are too uncertain or too distant."

— Elizabeth Downing, 3D Technology Laboratories

A Venture Capitalist's Perspective

The next speaker, a past president of the National Venture Capital Association, brought the perspective of the venture capital community to the goals of the ATP. David Morgenthaler, founder of Morgenthaler Venture Capital, observed that venture capital investments have grown dramatically in recent years, from \$4.9 billion in 1993 to almost \$50 billion in 1999. But, he continued, venture capitalists must be accountable to their investors, who demand a positive and fairly predictable internal rate of return, within a limited period (usually five years or less). In response to the classic question "At what stage in the maturity of a

[127] For a discussion of this key question see L. M. Branscomb, K. P. Morse, and M. J. Roberts, *Managing Technical Risk: Understanding Private Sector Decision Making on Early Stage Technology-based Projects*, NIST GCR 00787. April 2000. See also L.M. Branscomb and Philip E. Auerswald, *Taking Technical Risks, op. cit.*

technology should a venture capitalist invest?" the answer is clearly "When technical uncertainties are reduced." The enabling technologies in which the ATP typically invests represent too high a risk for private investors alone and are normally at too early a stage in their development.

"The venture capital business can be likened to a horse race," he said, "in which the technology is the horse, the management of the company is the jockey, the market is the race, and the venture capitalist is the owner and trainer. What we want is a great horse and a great jockey and to enter them in the Kentucky Derby (a huge market, in our homely analogy)." The ATP creates better horse races by financing both more discoveries and more enabling technologies, which lead to new and better products and services.

A Large Company Perspective

Kathleen Kingscott, Director of Public Policy for Science and Technology at IBM, noted that the process of research and development has changed in the past 20 years, with much greater emphasis on cooperation. Even a leading technology company like IBM, with an annual R&D investment of $6 billion, cannot go it alone anymore. Collaboration is increasingly vital, and IBM finds the ATP an excellent source of new technology and collaborators. Partnerships are sought after because they are a key means of reducing costs and risks and provide access to new, promising technologies. They also make technology transfer more efficient by improving communication among researchers and managers.

In the discussion that followed these presentations, David Morgenthaler pointed out that venture capitalists tend to specialize in particular areas of technology because they must compete to recruit the best young companies. A record of achievement in the appropriate field can make the difference.

Noting that the ATP's practice of making multiple awards to single companies has been criticized, Maryellen Kelley of the ATP's evaluation office asked Kathleen Kingscott about IBM's experience. Ms. Kingscott replied that IBM has participated in two ATP grants as a single company and seven as a member of joint ventures, with a shifting but overlapping set of partners.

Box I. A Venture Capitalist's Perspective on the ATP

"[The ATP] is an excellent program for developing enabling, or platform, technologies, which can have broad applications but are long-term, risky investments. Venture capitalists are not going to fund these opportunities, because they will feel that they are at too early a stage of maturity. Government can and should fund these technologies. In fact, it should do more than it is doing."

— David Morgenthaler, Morgenthaler Venture Capital

The ATP's Assessment Program

David Goldston, Legislative Director for Representative Sherwood Boehlert, introduced this panel, which considered the technical details of the ATP's assessment program. Rosalie Ruegg, Director of the Economic Assessment Office of the ATP, provided an overview of the ATP assessment program, followed by Irwin Feller who commented on the utility of economic assessment in federal programs such as the ATP.

From 1990 through 1999, Ms. Ruegg said, the ATP has co-funded 468 projects, with 1,067 participants and another 1,027 subcontractors. More than half of the projects are led by small businesses. More than 145 universities participate, as do more than 20 National Laboratories.[128] Funding of these projects by the ATP and industry has totaled about $3 billion, with each contributing about half. Of all federal technology programs, the ATP is probably the most given to rigorous economic assessment, principally through contracts with the National Bureau of Economic Research. An overview of the ATP's evaluation program can be found in the report summarizing the STEP Board's earlier meeting on the ATP.[129]

Measuring Impacts: Direct and Indirect Paths

The economic impacts of ATP projects can be measured in several ways, such as productivity gains, new businesses created, employment benefits, increases in gross domestic product (GDP) and improvements in the quality of life. The impacts of publicly funded R&D include both private returns to the company involved in the project and "spillovers" (impacts on others, including the company's customers, its competitors, and others who derive benefits or costs from the project's results).

The ATP traces these impacts along direct and indirect paths. The direct path follows the awardees and includes private returns to the particular companies directly involved in the ATP-funded projects and spillover benefits to their customers. The indirect path, no less important, involves the take-up of the knowledge generated by a project by others outside the project who have not directly contributed to the investment cost. Even if a project fails to find a commercial market—even if, in David Morgenthaler's analogy, the jockey falls off the horse—these indirect impacts continue to circulate through society as the knowledge is picked up and exploited by others. All of the indirect impacts can be considered spillovers from the original R&D. The impacts along the direct and indirect paths combined represent what economists call the social return of the project.

[128] Through the end of 2000, the ATP funded 522 projects with 1,162 participants and an approximately equal number of subcontractors. Through that time, 176 universities had participated.

[129] National Research Council, *The Advanced Technology Program: Challenges and Opportunities, op. cit*. pp. 71-80.

Assessment Tools

To track these impacts, the ATP uses a variety of statistical tools, including

- statistical profiling of applicants, projects, participants, and technologies;
- progress tracking of all projects and participants (through a business reporting system and other surveys);
- status reports for all completed projects;
- detailed microeconomic case studies of selected projects and programs;
- econometric and statistical studies of innovation, productivity, and portfolio impacts;
- limited use of macroeconomic analysis for selected projects;
- special issue studies; and
- development and testing of new assessment models and tools.

Ms. Ruegg also gave a short overview of the results of the evaluation of the first 50 completed projects, pointing out that a small number were terminated for a variety of reasons, the largest number were making progress but were as yet inconclusive, and a significant proportion of the projects were extremely promising.

Box J. Advancing the Art of Program Assessment

"ATP has gone beyond the efforts of other programs that have sought to measure direct benefits, by trying to measure indirect or "spillover" benefits. Measuring these impacts is a difficult, if not heroic, task. ATP's assessment techniques are at the state-of-the-art and, in many ways, have advanced the state of the art."

— Irwin Feller, Pennsylvania State University

Integrating "State-of-the-Art" Assessments

Economists' "irrational passion for dispassionate rationality," said Irwin Feller, of Pennsylvania State University, leads them to scrutinize dispassionately the impact of dispassionate rationality on public policy making—which has often been characterized by passionate irrationality.

In reviewing the ATP evaluation process, Dr. Feller commented on three topics: (a) technical aspects of the evaluation process itself, (b) use of the findings of that evaluation within the ATP, and (c) use of the findings of evaluation outside of the ATP.

Dr. Feller noted that the ATP has much to be proud of in its approach to assessment, compared, for example, with NIST's Manufacturing Extension Partnership Program (MEP). The ATP has gone beyond the efforts of other programs that have sought to measure direct benefits, by trying to measure indirect or "spillover" benefits. Dr. Feller remarked that the ATP's assessment techniques are clearly at the state-of-the art and in many ways have advanced the state of the art. Despite this accomplishment, a key question for the program is how effectively does the ATP use the results of the evaluation in its internal operations, notably in its project selection criteria?

A related issue is the impact of these excellent evaluations on decision makers outside the ATP, particularly in Congress. The ATP seems to be chronically beset by opposition in Congress to its very existence, and its budget tends to be erratic. Dr. Feller noted that Tolstoy once said, "Doing good will not make you happy, but doing bad will surely make you unhappy." The evaluator's corollary is "A good evaluation showing bad results will surely kill a program, but an evaluation that shows good results may not save a program." In closing, he observed that the real challenge is how to convert the ATP over time into a credible, institutionalized part of the federal science and technology apparatus, and thereby defuse the ideological objections of its opponents. If the program does well over time, this can happen. In any case, the ATP assessment program itself is a model for other partnership activities. As a dispassionate rationalist, he said, he would like to believe that it will be persuasive over time.

Mr. Goldston introduced the two discussants for the panel: Dr. Nicholas Vonortas of George Washington University and James Turner of the minority staff of the House Science Committee. Dr. Vonortas retraced the history of technology policy over the past two decades, in which he said that federal attempts to solve the "competitiveness" problem began as rather simplistic attempts to imitate the Japanese government and industry. In the end, though, these initiatives—and in particular the ATP with its serious approach to evaluation—have had the salutary effect of merging the two previously distinct literatures of business and economics. He also observed that the major European countries are more comfortable with programs of this kind, perhaps because in the past they relied less on the defense model.[130]

Solid Evaluations—Unstable Budgets

Jim Turner returned to the observation that the ATP is far ahead of other federal programs in its use of solid program evaluation. At the same time, as Dr. Feller had pointed out earlier, it remains in an unstable budgetary position in Congress. The contrast with the MEP is particularly striking. Both programs were

[130] Programs to support high-technology industry are widespread in Europe. Although often criticized as cumbersome or ineffective, over time regional and national programs to support industries such as semiconductors have had substantial positive impacts. See Thomas R. Howell, "An Overview of Government Policy Measures in Microelectronics," *op. cit.*

founded under the same statute (the 1988 Omnibus Trade and Competitiveness Act). The MEP was designed to have a strong base in each of the fifty states and therefore quickly became politically invulnerable. With its rigorous, apolitical approach and merit-based review, the ATP has never enjoyed that deep and broad support in the Congress.

Questions from the audience provoked a lively discussion of the political dilemma of the ATP. Dr. Lewis Branscomb endorsed Dr. Feller's comments on the uncertain link between positive economic evaluation and political support. Dr. Branscomb suggested that political evaluation as well as economic evaluation is needed.[131] He also suggested that few federal agencies practice intellectually sophisticated political evaluations.

David Goldston agreed that the ATP is well managed. Still, he said, many in Congress have fundamental concerns about the role of the federal government in the ATP, which are at the crux of one of the difficult—perhaps insoluble—questions about the ATP. Would the projects have been done anyway without the ATP? Are there more productive uses of federal money?

Jim Turner, Charlie Trimble, and David Goldston discussed the failure rate of the ATP projects. They agreed that too low a failure rate would suggest that the program was not tackling risky enough projects. At the same time, a high failure rate may be politically risky. It was pointed out that the ATP does terminate poorly performing projects—a good, if unusual, feature for a federal program.

Rosalie Ruegg assured Dr. Feller that the ATP management had taken steps to use the results of its evaluation to improve its selection process.

James Turner closed the discussion on a political note, observing that—ironically, perhaps—the drafters of the ATP's authorizing legislation had intended the program to be a political bolster for NIST, its parent agency. They had hoped that it would quickly develop a presence in all fifty states, something that has not yet occurred, as the chart below shows.

Stimulating R&D Investment

David Finifter, of the College of William & Mary, introduced this panel with the observation that, as an economist, he believed that the day's proceedings were making it clear that the ATP has greatly advanced the art of program evaluation.

Views from ATP Applicants

The first researcher was Dr. Maryann Feldman of Johns Hopkins University, who reviewed her study of the differences between winners and non-winners in

[131] For an informative discussion of U.S. technology policy, see L. M. Branscomb and J. Keller, editors, *Investing in Innovation, op. cit.* For a discussion of the ATP in comparison with the SBIR and other elements of the early-phase financing of new technologies, see L. M. Branscomb and P. E. Auerswald, *Taking Technical Risks, op. cit.*

ADVANCED TECHNOLOGY PROGRAM
Ongoing/Completed Projects
Project-Level Award Amounts ($M), Summed by State
(Forty-One Competitions: 1990-2000)

STATE	NUMBER OF PROJECTS*	ATP AWARDS ($M)	INDUSTRY-SHARE ($M)	TOTAL ($M)
Alabama	1	$3.3	$3.5	$6.8
Arizona	5	$16.6	$14	$30.6
California	120	$360.7	$353.6	$714.3
Colorado	8	$15	$8.5	$23.5
Connecticut	19	$55.3	$55.5	$110.8
Delaware	5	$9.4	$7.6	$17
Florida	7	$28.7	$29.8	$58.5
Georgia	6	$12.3	$7.2	$19.5
Illinois	21	$71.3	$75.7	$147
Indiana	2	$3.6	$3.2	$6.8
Iowa	2	$2.6	$1.4	$4
Louisiana	2	$3.8	$3.1	$6.9
Maryland	16	$50	$45	$95
Massachusetts	48	$96.2	$78.1	$174.3
Michigan	41	$182.4	$192.2	$374.6
Minnesota	17	$60.9	$70.3	$131.2
Missouri	1	$2	$1.4	$3.4
Nebraska	1	$2	$0.9	$2.9
New Hampshire	2	$4	$1	$5
New Jersey	26	$88.1	$95.5	$183.6
New Mexico	1	$2	$1.8	$3.8
New York	29	$72.1	$73.7	$145.8
North Carolina	7	$34.4	$33.1	$67.5
Ohio	17	$70.6	$71.6	$142.2
Oklahoma	2	$3.5	$3	$6.5
Oregon	8	$18.9	$17.7	$36.6
Pennsylvania	18	$57.1	$61.8	$118.9
Rhode Island	3	$4.4	$2.6	$7
South Carolina	3	$41.4	$48	$89.4
Texas	18	$59.7	$53.1	$112.8
Utah	8	$15.2	$12.9	$28.1
Virginia	10	$31.1	$23.3	$54.4
Washington	2	$3.9	$1.4	$5.3
Wisconsin	5	$9	$6.1	$15.1
State Count	**Project Count**	**Total ATP ($M)**	**Total Industry ($M)**	**Grand Total ($M)**
34	481	**$1,491.5**	**$1,457.6**	**$2,949.1**

**Project counts are based on location of "Lead" organization (single applicants/joint venture lead organizations).*

Note: Award and cost-share amounts listed for joint ventures represent amounts awarded to the joint venture as a whole. Not all participants in these joint ventures are necessarily located in one state—many other joint venture participants in a particular state may participate in joint ventures led by organizations in other states.

Source: NIST. Terminated projects are excluded.

the 1998 ATP competitions.[132] Dr. Feldman began her presentation by calling for a new approach to the study of the economic impacts of government R&D, using the ATP as an example of a new type of government program based on a public-private partnership. Traditional economic studies find that government funding displaces private investment but most studies have focused on defense procurement contracts. The ATP, by contrast, is a program in which the government is more of a partner than a customer; there are strong incentives to cooperate, share information, and undertake early-stage R&D, and government evaluation certifies that the technology is investment-worthy.

Differentiating Characteristics of the ATP. In assessing the ATP, Dr. Feldman suggested that it is important to understand that the program has the following critical characteristics that differentiate it from other government R&D programs:

- a focus on developing the economic benefit of early stage, high-risk, enabling innovative civilian technologies;
- an emphasis on the formation of partnerships and consortia;
- a rigorous, competitive selection process with an independent evaluation of the project's technical merit, commercial worthiness, and potential for broad-based economic benefits; and
- debriefings for those who apply but are not selected.

Surveying Winners and Non-winners. To learn about the impacts of these differences on ATP applicants, Dr. Feldman surveyed the 1998 applicants, both winners and non-winners, seeking answers to two questions: "Does the ATP application process reward risky, broad-based research projects?" and "Does the ATP award encourage subsequent investment by private investors?" The survey's findings show that the ATP, as intended, promotes new collaboration among awarded firms and partnerships with universities and government research institutions. She also found that awarded companies express greater willingness to share research results with other firms than do non-winners, which underscores the precompetitive nature of the selected projects. Interestingly, the survey also reveals that firms participating in the selection process find it to be fair and valuable. This view is held by both the award winners (as one might expect) and the majority of the firms who were unsuccessful in their applications (which one would not expect). This speaks well of the selection process.

Micro and Macro Impacts

Mark Ehlen, of the Office of Applied Economics in the NIST Laboratory for Building and Fire Research, presented an ATP-commissioned economic analysis

[132] See the paper by Maryann Feldman and Maryellen Kelley, "Leveraging Research and Development: The Impact of the Advanced Technology Program," in this volume.

of the micro- and macro-economic impacts of one ATP project: the Flow-Control Machining project carried out by a team led by Extrude Hone Corporation, a small machine tool company. He outlined the joint venture and its structure, discussed the process technologies that were developed, and reviewed the results of the economic analysis of the technologies in their first application in the automotive industry. His study estimated the expected economic impacts of the technology under two scenarios: one involving a brief penetration of the market and the other a longer and more significant penetration. The estimates show that, in either scenario, the vast majority of benefits are captured not by the company doing the R&D, but as spillovers to other firms and customers.

Advancing Manufacturing Technologies

Larry Rhoades, President of Extrude Hone Corporation, the company whose technology was assessed, reviewed his experience of two separate ATP projects, one on Flow Control Machining and another on 3D Printing. Ordinarily the company makes a gradual transition in introducing a new technology, from the complex geometries and difficult materials of the aerospace industry to the high-volume production of the automobile industry, over a period of 10 to 20 years. With the ATP project on Flow Control Machining, there was one giant leap, and the results are already in production throughout the industry. This transition, in fact, might not have occurred had it not been for the ATP.

Mr. Rhoades noted that we are moving beyond the traditional industrial R&D strategies, which begin with manufacturers' efforts to translate customers' desires and government regulations into product designs, and are then given to manufacturing engineers to devise appropriate processes. Markets are moving too fast now for this to occur. The ATP is an example of a new model, which involves designing processes and products together through a process of mutual feedback.

Discussion

Questions from the audience for this panel raised several points. Bernard Gelb of the Congressional Research Service asked Maryann Feldman about her statistical controls in the survey she reported. He observed that the 50 percent response rate is rather high, perhaps suggesting a self-selection bias by those with good things to say about the ATP. Dr. Feldman replied that there is no obvious statistical control for that bias, but the bias could just as easily have been negative, with non-winners complaining, as many in fact did. At the same time, she added, many successful applicants had not replied to the survey.

Bill Long of Business Performance Research Associates suggested to Dr. Feldman that she should consider surveying companies that have not applied in order to strengthen the case that ATP projects fund technologies that would not be able to attract private capital. Her team had considered that, she said, but had no way to construct such a sample. There are data on companies' funding histories before applying to the ATP, but not on companies that have never applied.

Lewis Branscomb suggested that Feldman's team approach venture capital firms for information on firms that they invest in. She replied that such a retrospective study—relying as it must on people's recollections—would introduce its own biases.

Bill Long asked Larry Rhoades whether it is typical of his industry to capture only 1 percent of the total value created by a new innovation, as documented by Mark Ehlen's study. Mr. Rhoades answered that the industry's ability to harness the value created in a manufacturing process is constrained. The typical company is small in relation to its major customers, so it does not have a strong negotiating position. Second, these companies need dozens of specific applications to make a new process pay for itself, and distributing the costs across these many customers is difficult.

Assessing Progress: Case Study Clusters

David Austin of Resources for the Future introduced this panel, which reviewed the latest assessment activities of the program.

Organ Transplants

David Ayares, Vice President of Research of PPL Therapeutics, announced that his company had received its first grant for the development of xenogenic organ transplants for human patients, which are being developed in genetically altered pigs. His company is a subsidiary of the British firm that made news with Dolly, the cloned sheep. The technology it is developing in the ATP project proved too risky for private investors, and the subsidiary company was on the verge of being closed by the parent company when it discovered and applied successfully to the ATP. Now it is the proud custodian of a litter of five little pigs, for which the ATP can take credit. Venture capitalists have expressed interest. More important, he said, if the technology proves successful, thousands of people's lives will be saved. The ATP has been decisive in creating this opportunity.

Counterfactual Cases

Todd A. Watkins, of Lehigh University, presented his innovative method of using case study methodologies to construct counterfactual cases in estimating the economic impacts of new technologies. In doing so, he is tracking both the economic value to participating firms and the knowledge spillovers to nonparticipating firms. By using "snowballing" interviews with customers, suppliers, and competitors, he and his team are attempting to map the technology diffusion process one level deeper. In addition, they have developed a "dynamic" model for the defender technologies, replacing the traditional static model.[133]

Tissue Engineering

Tayler Bingham of the Research Triangle Institute reviewed an RTI study of the economic impacts of seven completed ATP projects in medical technologies involving tissue engineering.[134] The study team modeled the entire process, from R&D to applications, to estimate the potential benefits of the technologies. Because health goods are not traded on markets, they developed a measure they called "quality-adjusted life year." (Briefly, a year of life in full health is assigned a value of 1; death is assigned a value of 0; and a year of life at less than full health is assigned a value between 0 and 1.) The study estimated the expected social return on the public (i.e., ATP) investment in these technologies at $34 billion, in net present value terms, or an internal rate of return (IRR) of 116 percent over the study period. The expected total social return on both public and private investments is estimated at $109 billion, net present value, or an IRR of 115 percent over the study period. The expected total private return on these investments is estimated at $1.6 billion in net present value ($914 million of it attributable to public funding), or an IRR of 12 percent over the study period.[135]

Economists in a Row…

The panel discussant was Henry Kelly, Associate Director for Technology, White House Office of Science and Technology Policy. He recalled Harry Truman's perhaps apocryphal dictum: "If you took all of the economists and laid them end to end, they'd point in all directions." Fortunately, one place they all point in the same direction is in their agreement that the social rate of return to R&D investments is much higher than the private rate of return to R&D investments.[136] It is beyond debate at this point. It is also true that the ATP is unique in the extent to which it has been evaluated, he said. If the program were not in place, addressing the problem of under-investment in commercializing R&D, we would need to invent something like it.

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[133] Todd A. Watkins and Theodore W. Schlie, "Diffusion Pathways for Advanced Photonics and Optoelectronics Technologies," paper presented at the Western Economics Association conference, Vancouver, British Columbia, 1 July 2000.

[134] S. A. Martin, D. L. Winfield, A. E. Kenyon, J. R. Farris, M. V. Bala, and T. H. Bingham, *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies: Preliminary Applications to Tissue Engineering Projects Funded from 1990 to 1996,* prepared by the Research Triangle Institute for the Advanced Technology Program, NIST GCR 97-737, April 1998.

[135] See the paper by Tayler H. Bingham, "Estimating Economic Benefits from ATP Funding of New Medical Technologies," in this volume.

[136] See Edwin Mansfield, *Estimating Social and Private Returns from Innovations Based on the Advanced Technology Program: Problems and Opportunities,* NIST GCR 99-780, January 1996.

Social Returns

In the stimulating debate of the issues presented by this panel, Lewis Branscomb observed that private investments in R&D, like public investments, produce excessive social returns. What market failures does the ATP address? The R&D "funding gap" (under-investment by the private sector) is the most often mentioned, but there are others. He urged the audience to consult his recent report *"Managing Technical Risk."*[137] Rosalie Ruegg replied that the ATP's purpose goes beyond compensating for the "funding gap," insofar as the program is designed to support projects with larger than average spillovers.

Todd Watkins picked up that point, suggesting that the ATP should try to identify the common factors of projects that have high spillovers so they can be used in the selection process.[138]

Assessing the ATP Assessment Program: Challenges and Policy Issues

The study director, Dr. Charles Wessner, opened this panel by encouraging a freewheeling discussion of ways to improve the ATP assessment program and, more broadly, the program itself. He first asked the invited speakers to briefly present their views, followed by an open discussion.

A New Environment

John Yochelson of the Council on Competitiveness said that the ATP must continue to improve steadily over time. Organizations either get better or they get worse. They do not stay the same. The program's mission—funding the advance of enabling technologies that would otherwise not be funded—has not changed in the past decade. Mr. Yochelson observed that the environment in which it operates, however, has changed dramatically in several ways:

- Concerns about the competitiveness of the U.S. economy have shifted from the production of competitive standard products and processes to the production of high-value or unique products and processes. Yochelson said that ATP responds to this shift.
- The process of innovation is increasingly global. Again, this change plays to the ATP's strengths.

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[137] L. M. Branscomb, K. P. Morse, and M. J. Roberts, *Managing Technical Risk, op. cit.* See also L. M. Branscomb and Philip E. Auerswald, *Taking Technical Risks*, *op. cit.*

[138] Adam Jaffe identified some of the common factors of projects that have high spillovers in his report as well as the difficulties in identifying them in advance. See Adam B. Jaffe, *Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program*, NIST GCR 97-708, Brandeis University and National Bureau of Economic Research, December 1996.

- The U.S. private sector has increased its focus on unique and high value products and services. This trend cuts the other way for the ATP, which is intended to compensate for companies' unwillingness to make such investments. How can the ATP address that issue?
- The U.S. economy is performing much better than it was in 1990, with a greater sense of competitive urgency on the parts of industry and government, and the federal budget is less constrained. These shifts would seem to favor the ATP.
- Economic power has grown more decentralized, with smaller, more entrepreneurial firms crowding out large firms as engines of growth and political power in the public sector flowing to states and localities. The ATP must take advantage of this change.

Maryann Feldman expressed her satisfaction with the day's discussion, although she suggested that in the future, more representatives of universities and state and local governments might be invited to participate because they are increasingly responsible for promoting technology development.[139]

MEP vs. ATP

William B. Bonvillian, Legislative Director and Chief Counsel to Senator Joseph Lieberman, drew the group's attention to the divergent political paths taken by the ATP and MEP. Both programs were founded at the same time and under the same legislation. The MEP developed and spread nationwide quite smoothly, with little meaningful opposition. The ATP's course has been erratic, particularly in terms of funding; today it is probably stable, but we should not be complacent about its future. Can we create a high-quality program, like the ATP, with similarly strong support? The best approach, he suggested, might be to take a page from the MEP's book, and bring governors and other elements of state government into the picture.

David Goldston agreed that the ATP seems to be "stuck" politically. One reason is that much of the program's original rationale—the specter of Japan, for example—is no longer taken seriously. And for many, the ATP represents an inappropriate role for government in helping industry. We need to develop a new rationale for the conditions of today. Otherwise the ATP cannot survive, let alone grow.

Reducing Transaction Costs

Todd A. Watkins of Lehigh University praised the ATP's role in reducing the transaction costs of building partnerships, or social networks. These social

[139] For data on state activities see National Science Foundation, *State Science and Engineering Profiles and R&D Patterns,* NSF 00-329, Arlington, VA: National Science Foundation, 2000.

networks are the basis of what many scholars today call "social capital," which is thought to promote a strong and flexible social order, but is not provided by markets. This social capital—expressed through collaborative relationships—may offer political advantages to the ATP's supporters. The program might stress this aspect of its mission more publicly, for example, through a variety of means, such as workshops and publications.

Micro, Not Macro, Analysis

Turning to another topic, Dr. Watkins expressed skepticism about the use of macroeconomic analysis in evaluating the ATP. Given the small size of the ATP's budget, no impact on the economy at large can reasonably be calculated. Even in the case of defense—where much effort is spent trying to identify positive spillovers into the economy—it is hard to make such a case.[140]

After this provocative series of presentations, the discussion was opened to questions from the audience.

Larry Rhoades said he was troubled by attempts to compare the MEP and the ATP. The two programs are very different. Each is successful in its own terms. To widen support for the ATP, he suggested, the program should work hard to apply the results of its evaluations and publicize its contributions to the economy.

Dr. Wessner asked the group to comment on the extent to which evidence from economic evaluation would be persuasive in political terms.

Sustaining a "Creation Myth"

David Goldston expressed doubt, observing that a basic problem for the program is that it has no sustaining "creation myth" to give it the aura of a national objective. Lewis Branscomb expressed his regret over the loss of the ATP focused programs. He suggested that political support for such an initiative might be modeled on the NSF K–12 education programs, which have been widely supported even though they trespass on a state and local prerogative.[141] The goal, he affirmed, is to attack a well-identified problem with enough resources to make a difference.

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[140] ATP has used the REMI model (Regional Economic Modeling, Inc.) in several cases after a microeconomic analysis has first been done and it has been determined that project effects can be reflected in REMI's input-output matrix and the project participants comprise a large part of the industry sector. Use of the model allows national effects to be estimated. An example was presented by Mark Ehlen in his case study of the application of a new machining technology in the automotive sector.

[141] Branscomb is referring to the NSF's Statewide Systemic Initiatives Program. Founded in 1991, the program makes grants to school districts for reforms aimed at fundamental transformation in pursuit of excellence in mathematics and science education. For an elaboration of this point, see Branscomb and Keller, eds., *Investing in Innovation, op. cit.*, pp. 492-493.

Mr. Bonvillian assured the group that he did not favor measures to water down the technical excellence of the ATP, but that the ATP should find some way to build grassroots support throughout the nation.

The group discussed the extent and the strength of local and sectoral support for the ATP. Maryellen Kelley observed that the ATP at one point had a “focused” (that is, sectoral) approach to some of its grants. In practice, however, the partnerships formed tend to be geographically diffuse.

David Goldston observed that MEP, unlike the ATP, had never suffered from organized and committed opposition, because most policy makers see it as an economic development program, not a science and technology program. The ATP might build wider support if it offered regional workshops or other economic development activities.

John Yochelson, David Goldston, and William Bonvillian discussed the pros and cons of regional and state-based services. A state-based program, Goldston said, would lend itself to political interference, harming the program’s merit basis. Yochelson suggested that organizing support through regional associations of states, crossing both state and party boundaries, could build support while limiting the potential for interference. Goldston argued that such an approach would create pressures to spread the program’s resources evenly around the country, without regard for technical excellence. Bonvillian expressed doubt that a regional organization would develop enough political support for stability, and he stressed the advantages of a program structure that allowed governors to take credit for successes.

Concluding Remarks
Charles Wessner, National Research Council

Dr. Wessner concluded the proceedings with a few observations on the program and its goals. The first is that this meeting had again emphasized the quality and diversity of the ATP assessment effort. Based on several years of reviewing federal partnerships, the ATP assessment program clearly surpasses other U.S. partnership programs with its rigor, scope, and independence.[142]

Second, perhaps because of its generic nature, the program seems to have been required to meet a higher standard of evaluation than many mission-oriented programs, which had relied on cooperative research agreements, or significantly larger generic programs such as the $1.2 billion SBIR program. The fact is that the ATP assessments, often conducted by independent economists, many under

[142] D. Mowery, *Using Cooperative Research and Development Agreements as S&T Indicators: What do We Have and What Would We Like?* presentation before National Science Foundation conference, *Workshop on Strategic Research Partnerships*, 13 October 2000, publication of proceedings pending. See also National Research Council, *The Small Business Innovation Research Program: Challenges and Opportunities, op. cit.*

contract with the National Bureau of Economic Research, strongly suggest that the program is meeting its goals. Few other federal programs have embraced this level and intensity of assessment and sought to apply its results as diligently as the ATP.

These observations are not meant to suggest that the program cannot be improved. Of course it can be, and the NRC report will make suggestions in that regard. Yet the ongoing evaluation of the program and its political difficulties should not be allowed to obscure what we have learned. There is a growing and increasingly weighty body of evidence indicating that:

1) The program is achieving its technology development goals in the fields of information technology and biotechnology. For example, the assessment program has recorded advances in new processes and procedures for printed wiring boards, the use of gallium arsenide to achieve improvements in integrated circuits, testing and aligning extremely precise coated mirrors, and enhancing data storage capabilities. In the field of biotechnology, it has supported advances in rebuilding lost or damaged human tissues, extracting more information from genetic sequencing of DNA, and developing non-toxic bioabsorbable polymers for repairing bone fractures.
2) Through its assessment program, close management oversight, and industry cost sharing, it has developed an effective self-correction mechanism. The assessment program helps management identify the impact of its awards. Close oversight ensures that projects that are not achieving specified goals can be, and are, cancelled.[143] As importantly, cost sharing ensures that private-sector partners withdraw from unpromising technical development of their own volition. Such mechanisms, and the flexibility they engender, are an essential feature of a modern technology development program.[144]

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[143] See Long, *Advanced Technology Program: Performance of Completed Projects—Status Report Number, op. cit*. This March 1999 report describes 50 projects of which 38 were completed and 12 were terminated (p. ix). For a discussion of the project achievements, see Chapters 2-8. Appendix B provides a brief description of why the projects were terminated (p. 131).

[144] See P. Grindley, D. Mowery, and B. Silverman, "SEMATECH and Collaborative Research: Lessons in the Design of High-Technology Consortia," *op. cit.,* p. 736.. The consortium's goals changed over time, reflecting the changing perceptions of its members' needs. The authors note that this operational flexibility is a strength and is probably essential in an industry evolving as rapidly as the semiconductor industry. See also R. R. Nelson, *Government and Technological Progress*, pp. 454-455. The cost-share feature of this program is an important and positive difference between the open-ended procurement failures documented by Cohen and Noll (*The Technology Pork Barrel, op. cit.*), where incentives for private contractors to withdraw from failing development programs were absent. Cohen and Noll also emphasize the need for flexibility in program management. *Ibid.*, p. vii.

3) The technologies ATP supports are meeting the program goals of
   a) improved efficiency and competitiveness (e.g., Extrude Hone's contribution to manufacturing efficiency and the environment);
   b) more rapid commercialization of new welfare-enhancing technologies with positive spillovers (e.g., the General Electric mammography diagnostic instrument);[145] and
   c) the development of significant new scientific discoveries, such as the PPL Therapeutics organ cloning.

Common Questions

Today's discussion was particularly useful in that it clarified some common questions or misunderstandings about the ATP. For example, questions are often asked about the need the ATP fills for a small company, why a large company would or should participate in a government-supported program, and what need is met by the ATP that is not already met by the well-developed venture capital industry in the United States. To take each in turn, Elizabeth Downing provided valuable insights concerning the challenges faced by a new start-up with a promising but technically challenging technology. Her views on the advantages of an ATP award in terms of administrative simplicity, long duration, and entrepreneurial control are particularly valuable. Her observations are especially relevant because she has had recent experience with a variety of federal programs and finds the ATP an excellent source of early finance for a technology of interest to a variety of federal mission agencies. Her views were complemented by Charles Trimble's observation that the ATP is an effective means to transfer funds, with minimal overhead, directly to researchers. The representative from IBM, Kathleen Kingscott, provided an equally valuable presentation explaining that the rapid pace of technological change and the diffusion of technical expertise means that even a major company with a large and successful internal R&D program finds it necessary to partner with small companies and universities through programs such as the ATP to identify new technologies. She described why IBM finds the ATP an effective vehicle to collaborate on the development of enabling technologies. Perhaps most instructive was the presentation by David Morgenthaler, who described the inherently different objectives and functions of venture capitalists and the ATP and affirmed the need for more government investments in support of promising technologies of the type undertaken by this program.

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[145] Recently approved for clinical use by the Food and Drug Administration, the new system represents a significant technological advance in breast cancer detection. It uses a unique amorphous silicon detector that provides high-quality imaging that can be digitally enhanced and rapidly verified. A 1995 ATP project awarded to General Electric and EG&G Reticon developed a new manufacturing process that significantly reduced the manufacturing cost of the amorphous-silicon panels used in the new detection system, making this superior detection system more affordable and available to a greater number of women. See http://www.nist.gov/public_affairs/update/upd000410.htm#Health

There was also much discussion of the extensive ATP assessment program. The outside assessments, complemented by in-house evaluations, demonstrate that the program is achieving its goals in many cases—though not all—and that the program is willing to terminate projects that are not achieving their goals.[146] As noted, this ability to self-correct in a timely manner is an important feature of the ATP. The willingness to accept the inevitable failures and cancel funding is in itself a valuable aspect of the program and one that is unfortunately only too rare. Government programs that can demonstrate an ability to meet their goals, particularly inherently uncertain R&D goals, are also rare. Programs that can positively contribute to these goals can make contributions to U.S. economic growth and international competitiveness. Indeed, as Professor Feller notes, the extensive ATP assessment program has itself led to significant progress in understanding important aspects of the U.S. innovation system and supported the development of methodologies for its analysis.

Changes Needed

As mentioned, there are clearly issues for the NRC assessment to address. For example, issues such as the timing and speed of the award process should be considered, as well as the possibility of concentrating resources in thematic areas, better integration of assessment results in the decision process, and the need to ensure sufficient program scale for maximum impact. There is the related possibility of the program undertaking more "work for others" as do a number of the DoE laboratories. This approach was suggested by Francis Collins of the National Human Genome Research Institute at the initial NRC meeting to review the ATP. These potential improvements might prove valuable to the new ATP management. Yet as the NRC study goes forward, it is important we note and record what the researchers and program participants—winners and losers alike—are saying. What they seem to be saying, and what the outside research shows, is that this is a federal program meeting its challenging goals.

[146] See William F. Long, *Advanced Technology Program: Performance of Completed Projects—Status Report Number 1, op. cit.*

III

FINDINGS AND RECOMMENDATIONS

Review of The Advanced Technology Program

Summary of Findings

In response to a Senate mandate, the National Institute of Standards and Technology (NIST) asked the National Research Council (NRC) to review the performance of the Advanced Technology Program (ATP) in light of its legislated goals and to make recommendations for improvements, where appropriate, in the operations of the program. This task was addressed by a committee previously formed under the direction of the National Academies' Board on Science, Technology, and Economic Policy (STEP) to carry out an assessment of government-industry partnerships. The Committee responsible for this analysis was not charged with a review of questions of principle with regard to the desirability of government-industry cooperation. Recognizing that partnerships are an integral part of the U.S. innovation system, the Committee has taken a pragmatic approach focusing its work on the operation and assessment of government-industry partnerships.[1]

Government-industry cooperation to achieve national goals has played a key role in U.S. economic development.[2] Continued U.S. leadership in technological progress is essential for the long-term growth of the domestic economy at a rising

[1] The scope of the Committee's work is described in the Preface.

[2] See the overview of the history of government-industry collaboration in the Preface of this volume. As discussed in the Introduction, the U.S. government has played a significant and supportive role in advancing technological progress in industries ranging from aircraft and biomedicine to information technology and the Internet. The ATP is a public-private partnership to develop new technologies with broad applications. The program makes competitive awards on a cost-share basis to individual companies and larger awards to joint ventures.

standard of living.[3] Substantial domestic U.S. investment in research and development—both public and private—is the prerequisite for sustaining U.S. economic growth in a global economy.[4] A leading role for the United States in the development and commercialization of new technologies is essential to the continued competitive success of U.S. industry in global markets. Governments around the world have recognized the importance of new technologies to their economies and have encouraged public-private partnerships to develop and anchor them within their national economies. The long-term goal of these programs is to achieve greater productivity growth through the creation of knowledge that can be applied to industrial processes, products, and services.[5] The logic behind government funding of certain types of R&D activities is that government awards provide incentives to firms to undertake high-risk R&D projects with substantial potential benefits for the economy as a whole.[6] In the middle of the 1980s the United States began focusing more attention on cost-shared partnerships as a means of developing new technologies.

As noted in the Introduction, the Committee's assessment of the Advanced Technology Program is contributing to the Committee's review of government-industry partnerships programs in the United States and abroad. This assessment of the ATP should thus be understood as one element of the Committee's multi-year study of a wide variety of partnerships. Carrying out this analysis of the ATP

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[3] See Michael Borrus and Jay Stowsky, "Technology Policy and Economic Growth," in Lewis Branscomb and James Keller, editors, *Investing in Innovation: Creating a Research and Innovation Policy,* Cambridge, MA: MIT Press, 1998. The contribution of technology to economic growth is now well recognized. See P. Romer, "Endogenous Technological Change," *Journal of Political Economy*, 98(5):71-102, 1990. See also G. Grossman and E. Helpman, *Innovation and Growth in the Global Economy*, Cambridge, MA: MIT Press, 1993.

[4] Romer, "Endogenous Technological Change," *op. cit*.; Borrus and Stowsky, "Technology Policy and Economic Growth," *op. cit*. See also National Research Council, *Allocating Federal Funds for Science and Technology*, Washington, D.C.: National Academy Press, 1995. The report notes that federal investments in R&D have produced enormous benefits for the nation's economy, national defense, health, and social well-being. *Ibid.*, p. 3.

[5] See the paper by Maryann P. Feldman and Maryellen R. Kelley, "Leveraging Research and Development: The Impact of the Advanced Technology Program," in this volume.

[6] As noted by Feldman and Kelley in this volume, "The logic for public investment is that, in the long run, the economic benefits to consumers, other firms and the larger national economy will exceed the private returns realized by the firm that received the research award, and thus justify the public investment." *Ibid*. The rationale for government funding of certain types of R&D activities, as articulated by Zvi Griliches, is that this funding encourages firms to undertake R&D projects in which the public rate of return exceeds the private rate of return. This includes, for example, the case in which an industry as a whole may benefit from the development of an enabling technology. Private firms typically use some predetermined benchmark rate of return known as a hurdle rate. The project will only be acceptable if the expected rate of return is above that benchmark. By reducing the cost of the project, government funding will increase the expected rate of return and may make private companies willing to pursue them. See Z. Griliches, "The Search for R&D Spillovers," *Scandinavian Journal of Economics*, 94(Supplement):29-47.

has informed the Committee's deliberations and allowed for comparative points of view on a range of partnership activities. As part of this assessment, the Committee organized two major symposia and a workshop to review the program's operation and also drew on the substantial body of independent analysis of the program. The initial symposium provided an overview of the program in terms of its goals, operations, assessment, achievements, and challenges while providing an opportunity for critics to voice their views. The symposium summarized in this volume focused on possible improvements to the program, findings from the ATP assessment effort, issues such as "crowding out" and the relationship of the ATP to venture capital, the roles and needs of large companies in such a program, and feedback from users, some of whom have received other types of awards. The collection of papers included in this volume provide insights into the operation and impact of the ATP and are illustrative of the substantial program of external and internal research it has under way. The meetings and research are of course complemented by the exceptional expertise of the Committee responsible for the NRC review of government-industry partnerships.[7] Keeping in mind the limitations and advantages of the Committee's analysis, the core findings and recommendations of the study are listed below.

Core Findings and Recommendations[8]

1. The Committee finds that the Advanced Technology Program is an effective federal partnership program. The selection criteria applied by the program enable it to meet broad national needs and help ensure that the benefits of successful awards extend across firms and industries. Its cost-shared, industry-driven approach to funding promising new technological opportunities has shown considerable success in advancing technologies that can contribute to important societal goals such as improved health diagnostics (e.g., breast cancer detection), developing tools to exploit the human genome (e.g., colon cancer protection), and improving the efficiency and competitiveness of U.S. manufacturing.[9]
2. The program's peer review of applicants for both technical feasibility and commercial potential supports its goal of helping advance promising new tech-

[7] The members of the Committee are listed in the front matter.

[8] These summary findings and recommendations are elaborated and documented below. In addition to the papers and proceedings in this volume, the Committee issued National Research Council, *The Advanced Technology Program: Challenges and Opportunities*, Washington, D.C.: National Academy Press, 1999. The ATP assessment program also provides extensive documentation regarding the contributions of the program. See Annex D in this volume. See also William F. Long, *Advanced Technology Program: Performance of Completed Projects: Status Report Number 1*, NIST Special Publication 950-1, March 1999.

[9] See Section I in this chapter. For a summary of the differentiating characteristics of the ATP, see Maryann Feldman's analysis in Section C of the Introduction and the study by Feldman and Kelley, "Leveraging Research and Development: The Impact of the Advanced Technology Program," both in this volume.

nologies that are unlikely to be funded through the normal operation of the capital markets.[10]

3. The program has set a high standard for assessment involving both internal and independent external review. The quality of this assessment effort lends credence to the program's evaluation of its accomplishments.[11]
4. The extensive assessments of the program show that it appears to have been successful in achieving its core objective, that is, enabling or facilitating private sector R&D projects of a type, or in an area, where social returns are likely to exceed private returns to private investors.[12,13]
5. The Committee does recommend a series of operational improvements designed to make this program more effective and suggests several measures

[10] With regard to the ATP selection process see the presentation by former ATP Director, Lura Powell, in the first volume of this study, National Research Council, *The Advanced Technology Program: Challenges and Opportunities*, *op. cit*., pp. 53-56; with regard to the role of venture capital finance and the need for a bridging mechanism, see the statement by Todd Spener of Charter Financial in the same volume, pp. 90-91, as well as the presentation by Joshua Lerner of the Harvard Business School, pp. 88-90. See also the presentation by venture capitalist David Morgenthaler in Panel I of the Proceedings of this volume and the summary of his statement in Section C of the Introduction to this volume. See also Lewis M. Branscomb and Philip E. Auerswald, *Taking Technical Risks: How Innovators, Managers and Investors Manage Risk in High-Tech Innovation,* Cambridge: MIT Press, 2001, Chapter 5 and *passim*.

[11] See Section I in this chapter and the description of the program, its current results, and the ATP assessment effort by Rosalie Ruegg and the positive review of the assessment program by Irwin Feller of Pennsylvania State University in Panel II in this volume. See also the panel discussion led by Richard Nelson of Columbia University, including the description of the ATP assessment, its early beginnings, and its focus on tools for assessing technology spillovers in National Research Council, *The Advanced Technology Program: Challenges and Opportunities*, *op. cit*., pp. 71-80.

[12] See, for example, the paper by Maryann Feldman and Maryellen Kelley, "Leveraging Research and Development: The Impact of the Advanced Technology Program," in this volume. The study by Albert N. Link, "Enhanced R&D Efficiency in an ATP-funded Joint Venture," documents the impact of an ATP joint venture designed to reduce the costs and timing required to develop a suite of new technologies for the U.S. printed wiring board industry. The study finds a dramatic effect on R&D efficiency, resulting in cost savings on the order of $35 million while reducing cycle times for new product and process development. The project resulted in productivity improvements for member companies, diffusion of new technology to other producers, and improved competitive positions for and retained employment at participating companies. The study by David Austin and Molly Macauley, "Estimating Future Benefits from ATP Funding of Digital Data Storage," estimates substantial consumer welfare gains from ATP-funded innovations in digital data storage although the final impact is dependent on the adoption of the technologies. Similarly, the paper by Tayler H. Bingham, "Estimating Economic Benefits from ATP Funding of New Medical Technologies," projects substantial social returns, much larger than the projects' private returns, primarily due to the projected positive spillovers to patients treated with new technologies. These technologies focus on the diagnosis and treatment of cancer; the treatment of diabetes, damaged ligaments and tendons; and the transplanting of xenogenic organs. The overview of the progress of ATP awards by Rosalie Ruegg, "Taking a Step Back: An Early Results Overview of Fifty ATP Awards," documents both commercialization progress and knowledge creation and dissemination. The latter is documented through outside recognition of the project's technical accomplishments, patents filed and granted, patent-tree citations, collaborative

designed to bring the benefits of the ATP to other national initiatives and to state technology programs through enhanced cooperation.[14]

I. Accomplishments of the Advanced Technology Program

A. Meeting Legislative Goals:

The Advanced Technology Program is achieving the goals ascribed to the program in the Omnibus Trade and Competitiveness Act of 1988. As initially stated, its goals were "to assist U.S. business in creating and applying the generic technology and research results to (1) commercialize significant new scientific discoveries and technologies rapidly and (2) refine manufacturing technologies." (P.L. 100-418). The ATP emphasizes economic growth and advances the competitiveness of U.S. firms by fostering technologies with potentially large net social value for the nation that might not otherwise emerge in time to maximize their competitive value.[15]

B. Supporting Enabling Technologies:

The ATP focuses its support on enabling technologies that face substantial technical barriers yet which also have the potential for broad-based economic benefits. Program goals and examples of technologies illustrating the ATP approach and meeting the program's current operational objectives are:

1. Improved manufacturing efficiency and competitiveness. ATP contributions are illustrated by Extrude Hone's contribution to manufacturing efficiency and the environment and by the successful U.S. Printed

relationships, and knowledge disseminated through new products and processes. Ruegg records substantial evidence that benefits are extending well beyond those captured by award recipients. The papers cited above are included in this volume.

[13] For an excellent review of the factors affecting the generation and impact of social returns or spillovers, see Adam B. Jaffe, *Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program,* NIST GCR 97-708, December 1996. For additional ATP-supported research on social benefits, see Edwin Mansfield, *Estimating Social and Private Returns from Innovations Based on the Advanced Technology Program: Problems and Opportunities,* NIST GCR 99-780, January 1996; William F. Long, *Performance of Completed Projects, Status Report Number 1*, *op. cit.*; Wesley M. Cohen and John Walsh, *R&D Spillovers, Appropriability, and R&D Intensity: A Survey-Based Approach,* Gaithersburg, MD: National Institute of Standards and Technology, Forthcoming; and Michael S. Fogarty, Amit K. Sinha, and Adam B. Jaffe, *ATP and the US Innovation System: A Methodology for Identifying Enabling R&D Spillover Networks with Application to Microelectro-mechanical Systems (MEMS) and Optical Recording,* Gaithersburg, MD: National Institute of Standards and Technology, Forthcoming.

[14] See Sections II and III in this chapter.

[15] The Introduction to this volume provides the policy context which led to the creation of the ATP and other cooperative programs and summarizes legislation designed to encourage cooperative technology programs. The legislation establishing the ATP is reproduced in Annex A.

Wiring Board (PWB) consortium.[16] Other contributions include an "ion implantation" technology to reliably process larger, and hence more productive, 300mm wafers economically. The ATP helped fund the development of advance process control (APC) technology for semiconductor production, which increases process consistency and yield.[17] Working with large and small companies, the program also helped develop a novel insulating material to improve performance of computer chips.[18] These innovations should help maintain the exceptionally high historical annual growth in productivity, on the order of 25-30 percent, which characterizes the semiconductor industry.

2. More rapid commercialization of technologies with positive spillovers, such as the mammography diagnostic instrument recently brought to market.[19] Work is also under way to develop miniaturized DNA analyzers designed to increase the speed of research and medical testing for diseases such as HIV, strep infections, or cancer.[20]

3. Contributing to the development of technologies embodying recent scientific discoveries, such as the award to PPL Therapeutics to develop a way to produce valuable stem cells from adult human cells, possibly creating a non-controversial alternative to the use of embryonic stem

[16] For a discussion of the manufacturing and environmental efficiencies made possible by Extrude Hone's advanced manufacturing processes, see the presentation by Larry Rhoades in Panel III of this volume. For a summary of the accomplishments of the PWB consortium see the analysis by Albert Link, "Enhanced R&D Efficiency in an ATP-funded Joint Venture" in this volume.

[17] The APC technology was developed in cooperation with SEMATECH and leading U.S. firms, such as Honeywell, Inc., Advanced Micro Devices, and IBM, among others.

[18] Developed by Texas Instruments and NanoPore, Inc., a small New Mexico-based company, the insulator is called Xerogel, which consists of a highly porous, glass material used as a low dielectric constant insulating layer in integrated circuits. The innovation has led to an estimated twenty patents and patent applications and represents a positive development for U.S. industry.

[19] Recently approved for clinical use by the Food and Drug Administration, the new system represents a significant technological advance in breast cancer detection. It uses a unique amorphous silicon detector that provides high-quality imaging which can be digitally enhanced and rapidly verified. A 1995 ATP project awarded to General Electric and EG&G Reticon developed a new manufacturing process that significantly reduced the manufacturing cost of the amorphous-silicon panels used in the new detection system, making this superior detection system more affordable and available to a greater number of women. See http://www.nist.gov/public_affairs/update/upd000410.htm#Health. See also footnote 40 in this chapter.

[20] See National Research Council, *The Advanced Technology Program: Challenges and Opportunities*, *op. cit.*, p. 55. Microtechnologies under development offer significant advances in the convenience and speed of DNA analysis. One such company, Affymetrix, has developed chip systems which can detect genetic variations related to HIV, cancer, and drug metabolism. The company has also received a grant from the Human Genome Research Institute.

cells. Stem cells hold the promise of fighting diseases ranging from heart failure to Parkinson's.[21]

4. Catalyzing and supporting research partnerships between industry on the one hand and U.S. university researchers and federal laboratories, on the other. Through 2000, 176 universities have been involved in the program, participating in over half (56 percent) of the program's 522 projects, either as full participants or subcontractors. Some 50 projects have included federal laboratories. These partnerships help speed the transfer of publicly-funded basic research and expertise to industry.[22]

C. An Exceptional Assessment Effort:

The ATP assessment program has produced one of the most rigorous and intensive efforts of any U.S. technology program. This program has two elements: an in-house effort based at NIST Headquarters and an external effort contracted with the independent National Bureau of Economic Research.[23] The quality, quantity, and analytical range of these studies are impressive. Over 58 case studies and other assessments have been completed; substantial additional work is under way.[24] With regard to this assessment program, several points emerge:

1. It is important to note that these studies, by their very nature, do not endorse every aspect of the program. They do provide valuable insights into the operation and impact of the program.

2. The broad scope of the studies offers insights into the operations of the U.S. innovation system, for example, with respect to early-stage

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[21] See Erika Jonietz, "Sourcing Stem Cells: Could New Research End the Embryo Debate?" *Technology Review*, January/February 2001, p. 32.

[22] For an earlier discussion of this point, see the presentation in Panel II by Rosalie Ruegg, Director of the ATP Economic Assessment Office at the time of the conference. The universities most involved in ATP projects include: Stanford University; the University of Michigan, Ann Arbor; the Massachusetts Institute of Technology; Cornell University; Johns Hopkins University; the University of Minnesota; Carnegie Mellon University; Pennsylvania State University; the University of California, Berkeley; and North Carolina State University.

[23] See the discussion of the ATP assessment program in Panel III of National Research Council, *The Advanced Technology Program: Challenges and Opportunities, op. cit.,* pp. 70-82, especially p. 79. This section describes ATP's substantial involvement of outside experts, both in the selection process through peer review, and the valuable input provided from the outset of the program through consultations with leading economists from the National Bureau of Economic Research (NBER), which included important contributions by Professors Zvi Griliches and Edward Mansfield. This collaboration continues under the overall direction of NBER's Adam Jaffe.

[24] See Annex D of this volume for a list of studies commissioned by the ATP Economic Assessment Office.

finance of promising technologies and the impact of the intellectual and economic spillovers derived from the program.[25]

3. These studies are also making a contribution to our understanding of the U.S. innovation system and to the development of methodologies to measure the impact of federal and state technology programs such as the ATP.[26]

4. Few other federal technology programs have embraced this level and intensity of assessment and sought to apply its results as diligently as the ATP.[27]

II. Recommendations to Improve the Program

A. Extend the window for award applications, accelerate the decision-making process for awards, and extend substantially the period in which awards can be made: New, commercially-relevant technologies are often time sensitive. Fixed periods for firms to apply to the program and long delays in notification of awards may reduce the attractiveness of the pro-

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[25] National Research Council, *The Advanced Technology Program: Challenges and Opportunities, op. cit.*, pp. 79-80. See also Adam Jaffe, "The Importance of 'Spillovers' in the Policy Mission of the Advanced Technology Program," *Journal of Technology Transfer*, 23(2):11-19, 1997; E. Mansfield, *Estimating Social and Private Returns from Innovations Based on the Advanced Technology Program: Problems and Opportunities, op. cit.*; Wesley M. Cohen and John Walsh, *R&D Spillovers, Appropriability, and R&D Intensity: A Survey-Based Approach*, *op. cit.*; and D. Mowery, J. E. Oxley, and B. S. Silverman, *Knowledge Spillovers and R&D Joint Ventures*, Gaithersburg, MD: National Institute of Standards and Technology, Forthcoming.

[26] As noted above, an excellent example is the recent work by L. M. Branscomb and P. E. Auerswald, *Taking Technical Risks, op. cit.* Initially sponsored by the ATP, this volume reviews some of the factors affecting early-stage financing and notes a serious gap between the creation of an idea and its realization in a technology that meets market requirements for investors. With regard to interaction with state programs see Marsha R.B. Schachtel and Maryann P. Feldman, *Reinforcing Interactions Between the Advanced Technology Program and State Technology Programs, Volume I: A Guide to State Business Assistance Programs for New Technology Creation and Commercialization*, Washington, D.C.: U.S. Department of Commerce, April 2000.

[27] For example, the SBIR program, currently allocated over $1.2 billion annually, is six times larger than the ATP, yet it has been subject to almost no systemic external assessment, apart from a series of GAO reports and the recently completed National Research Council study, *The Small Business Innovation Research Program: An Assessment of the Department of Defense Fast Track Initiative*, Washington, D.C.: National Academy of Press, 2000. Similarly, widely used cooperative research and development agreements (CRADAs) normally have limited assessment mechanisms. These limitations are described by D. Mowery in "Using Cooperative Research and Development Agreements as S&T Indicators: What do We Have and What Would We Like?" a presentation before the National Science Foundation conference, *Workshop on Strategic Research Partnerships*, 13 October 2000, publication of proceedings pending. Some partnership programs have benefited from regular assess-

gram, in particular to new, small firms. Faster decision-making also would enhance the value of the debriefing process for unsuccessful firms.[28] This revolving application process will provide greater opportunity for applicants. It will also give the ATP management earlier and more accurate information concerning the rate of awards than is available under an annual award process.[29]

B. Retain the debriefing process for unsuccessful applicants: Unsuccessful awardees find the debriefing process after an unsuccessful application to the ATP to be valuable even though more than three-fifths of the non-winners do not proceed with any aspect of the R&D project that they proposed to ATP.[30]

C. Concentrate a significant proportion of the awards in selected thematic areas: One of the key features of the ATP is its use of general competitions, which are open to proposals from all areas of technology. The goal of the program is to compensate for market imperfections that result in under-investment in certain types of technologies, a goal that distinguishes it from mission-oriented (and mission-constrained) R&D programs.[31] These general competitions should be maintained. At the same time, they could be usefully supplemented by allocating a proportion of ATP funding in selected thematic areas where the current technological opportunities are particularly promising for broad economic or social benefits. Awards to thematic areas can also be a means of addressing elements of important national missions and of generating synergies between related projects, and among companies, laboratories, and universities in areas of current technological promise. In

ment such as the Program for Next Generation Vehicles and the Advanced Battery Consortium. See National Research Council, *Review of the Research Program of the Partnership for a New Generation of Vehicles: Sixth Report*, Washington, D.C.: National Academy Press, 2000, and National Research Council, *Effectiveness of the United States Advanced Battery Consortium as a Government-Industry Partnership*, Washington, D.C.: National Academy Press, 1998.

[28] For a description of program modifications undertaken by the ATP management in the course of this review, see Alan P. Balutis and Barbara Lambis, "The ATP Competition Structure," in this volume.

[29] Faster decision making has also been a concern for the SBIR program. The Department of Defense launched a successful initiative known as the Fast Track for firms able to demonstrate the ability to attract third-party finance. See National Research Council, *The Small Business Innovation Research Program: An Assessment of the Department of Defense Fast Track Initiative, op. cit., passim.*

[30] See the paper by Maryann P. Feldman and Maryellen R. Kelley, "Leveraging Research and Development: The Impact of the Advanced Technology Program," in this volume.

[31] J. Lerner and C. Kegler, "Evaluating the Small Business Innovation Research Program: A Literature Review," in National Research Council, *The Small Business Innovation Research Program: An Assessment of the Department of Defense Fast Track Initiative*, *op. cit*., pp. 309-314. For an informed discussion of U.S. technology policy see L. M. Branscomb and R. Florida, "Challenges to Technology Policy in a Changing World Economy," in Branscomb and Keller, *Investing in Innovation, op. cit.*

these cases, the program should attempt to reap the higher returns from realizing complementarities and synergies among projects and R&D-performing institutions.[32]

D. Enhance current efforts to integrate assessment results into the decision process: As noted, the quality of the ATP assessment effort is a major attribute of the program. The integration of the results of the assessments must remain a major goal of the program.[33] The early release of outside assessments to the research community would facilitate the dissemination of the research results.

E. Increase the Nation's Return on the Operation of the Program:

1. Maximizing Return: As noted above, the program is achieving its goals.[34] It has a deserved reputation as a program that is well managed and under which awards are fairly awarded.[35] In our view, based on this review of the program, the ATP could use more funding effectively and efficiently, consistent with the goals set for the program. A more predictable funding base would also ensure that the program continues to attract quality proposals, provide flexibility to address new opportunities and ensure the maximum return on existing investments.

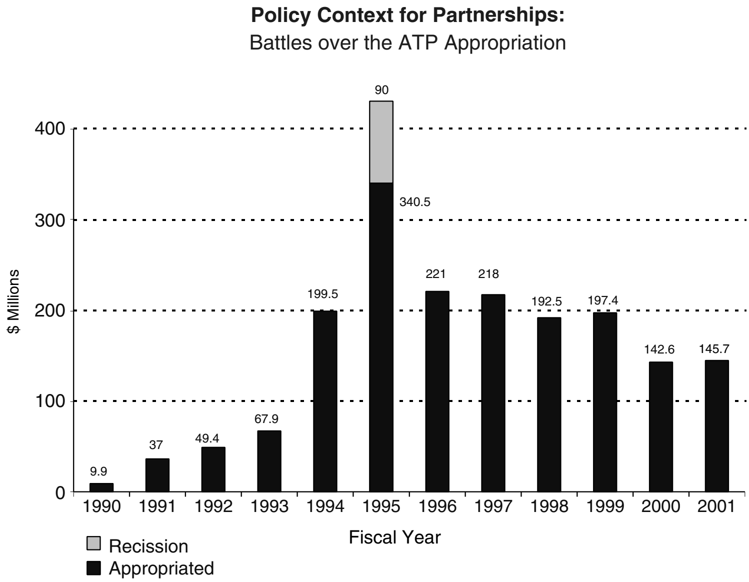
2. Stability for R&D Funding: In any case, every effort should be made to provide greater stability in the funding of the program. The current instability creates uncertainty for participants and potential

[32] The generation of "social capital" made possible by these awards underscores the role of government finance for technological innovation.

[33] See Panel II, in this volume, where current efforts to integrate evaluation findings are described.

[34] This does not mean that all awards are crowned with success. As would be expected for a high-risk R&D program, a significant portion of the awards do not succeed. This experience strongly parallels the experience of venture-backed investment. For example, one study found that out of a sample of 794 venture capital investments made over three decades, only 22.5 percent ultimately succeeded in going public: see P.A. Gompers, "Optimal investment, monitoring, and the staging of venture capital," *Journal of Finance* 50(5):1461-1489. Concerning program evaluation, see the discussion in Panel II, especially the remarks by Irwin Feller of Pennsylvania State University, in this volume and Panel IV, especially the presentation on "Economic Returns to New Medical Technologies" by Taylor Bingham of the Research Triangle Institute, also in this volume. Concerning program accomplishments (and failures), see the overview provided by Rosalie Ruegg, "Taking a Step Back: An Early Results Overview of Fifty ATP Awards," in this volume.

[35] Feldman and Kelley, "The Case for Government R&D Additionality," *op. cit*. The authors provide evidence that the investment community attaches value to the ATP awards through the highly selective and competitive nature of the award process. A significant percentage of even the non-winners in the selection process found the debriefing process to be helpful suggesting useful guidance for improving the firm's technical and/or business planning was made available.



applicants about the funding of multi-year program commitments and is particularly difficult for small firms.[36]

F. Continue Focus on Small Business: A significant portion of the program funds (i.e., more than 60 percent) are awarded to small business. This reflects small business's unique capabilities as a source of low-overhead innovation.[37] Notwithstanding this recognition of the innovative capabilities of small business, the diversity of the ATP awards, involving both large and small companies, is an important feature of the program, and should be retained (see G below). The substantial size of the ATP awards, their multiyear disbursement, and the opportunity to collaborate with other institutions (e.g. universities) and larger firms make ATP funding particularly attractive to small firms. The ATP can thus contribute to the development of new technologies that meet its criteria of broad social benefits and enhance returns on the U.S. investment in research.

G. Retain Joint Ventures and Large Company Involvement: The participation of large companies is a unique and valuable characteristic of the

[36] Roger Noll and Linda Cohen emphasize the need to avoid large swings in annual funding for R&D programs. See *The Technology Pork Barrel*, Washington, D.C.: The Brookings Institution, 1991, p. vii.
[37] David B. Audretsch and Roy Thurik, *Innovation, Industry, Evolution, and Employment*, New York: Cambridge University Press, 1999.

ATP.[38] Large companies bring unique resources and capabilities to the development of new technologies and can be valuable partners for technologically innovative companies new to the market.[39] The participation of larger companies can also ensure better access to downstream markets for the small firms with which they collaborate under this program.[40] Accordingly, awards to joint ventures involving large companies should be retained. The current 60 percent funding requirement for large companies should also be retained; it should not, however, be significantly increased.

H. Coordinate ATP with SBIR: The SBIR and the ATP programs are different in important ways. However, they can be understood as separate steps on a national innovation ladder. In cases where applicants to the ATP do not have sufficiently developed business plans, but do have sound technologies, they might well be remanded *automatically* to an appropriate SBIR program. To the extent their technology has met the requirements of the ATP, SBIR program managers could be assured of the potential of the proposed technology.[41]

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[38] Dr. Mary L. Good describes the leverage offered by an ATP award to win internal support for a promising technology at Allied Signal. As Dr. Good describes it, the award fit the conditions associated with ATP (i.e., early technology development, an enabling technology, and collaborative work with universities resulting in the creation of a new material). She adds that the capabilities of a large company (i.e., expensive equipment and experienced technologists) were crucial to the success of the award. L. M. Branscomb et al., *Managing Technical Risk: Understanding Private Sector Decision Making on Early Stage, Technology-based Projects,* NIST GCR 00787, prepared for the Advanced Technology Program, April 2000, p. 42

[39] For a further discussion of this point see C. Hill, "The Advanced Technology Program: Opportunities for Enhancement," in Branscomb and Keller, *Investing in Innovation, op. cit.*, pp. 159-160. Hill suggests that because R&D decisions are often decentralized, large firms may operate much like independent, small firms particularly for projects that have high ratios of social to private returns.

[40] The development and marketing of the digitally-enhanced mammography diagnostic instrument (referred to in footnote 19) illustrates the synergy between large and small firms. The substantial marketing advantage of an established firm such as GE means the benefits of this new technology are rapidly and widely distributed. The laboratory manager responsible for developing the mammography diagnostic technology, Dr. Bruce Griffing, states that this promising technological development might well not have occurred in the absence of a government R&D award from the ATP. As noted above, this diagnostic system produces substantially fewer false positives. The lower false positive diagnoses reduce the need for expensive "work-ups" with the associated health care costs and personal trauma. Over time, the technology has the potential to virtually eliminate costs associated with film storage, retrieval, and transmission. The social benefits or spillovers appear substantial.

The development of this technology also illustrates the impact federal R&D awards can have on decision making in large companies where multiple options, established hurdle rates, and technological and market uncertainties mitigate against even promising technologies. As Dr. Griffing remarked in a recent seminar, "There is a valley of death for new technologies, even in the largest companies." *Between Invention and Innovation: Mapping the Funding for Early Stage Technologies*, Carnegie Conference Center, 25 January 2001, Washington, D.C.

[41] To a limited extent, this process already occurs in reverse. Successful applicants to an SBIR program may subsequently apply to the ATP. However, firms that do not qualify in an early stage of their development for an ATP award may well meet the different criteria for an SBIR award. There are cases

III. New Initiatives for the Program

A. Increased Collaboration on National Initiatives:

ATP's collaboration with agencies responsible for national initiatives such as the Human Genome should be substantially increased. The Advanced Technology Program has established a "core competency" in its ability to screen, select, monitor, and assess projects of technological and commercial promise. As such, the ATP would be a valuable partner to research agencies and SBIR programs by working with them to develop valuable enabling technologies based on their investments in health and other areas such as environmental remediation.[42]

The National Institutes of Health have shown unparalleled capability in the funding of basic health-related research and have made enormous progress in specific areas such as the sequencing of the human genome. However, NIH investments tend to be focused on the generation and demonstration of new research ideas. The comparative advantage of the ATP is its ability to provide R&D funds to stimulate specific sectors and companies with the potential to develop these new ideas as commercial products and therefore make them available to a much wider group of users. An example of this approach is the ATP support for DNA tools, which is converting research findings into methods, devices, and reagents that actually work.[43] This type of collaboration between the ATP and health researchers should continue and expand.

B. Matching Grants by States:

1. In some states, firms that receive ATP awards are currently eligible for grants from the state government. The NIST management should establish a regular outreach program to coordinate awards after the review process (or in conjunction) with state development programs.

2. Matching State Funds: Consideration should be given to providing matching state funds for ATP awardees.[44] Expanding the ATP's interaction with state programs to support high-technology companies

where firms have progressed from an early SBIR award to an ATP award. See Donna Fossum, et al, *Discovery and Innovation: Federal Research and Development Activities in the Fifty States, District of Columbia, and Puerto Rico,* Science and Technology Policy Institute, MR-1194-OSTP, 2000.

[42] See the statement delivered by Jeffrey Schloss on behalf of Francis Collins, the Director of the National Human Genome Research Institute at the National Institutes of Health, in the first volume of the Committee's review of the ATP. See National Research Council, *The Advanced Technology Program: Challenges and Opportunities, op. cit.,* pp. 56-59.

[43] *Ibid*., p. 58.

[44] The ATP currently refers potential recipients of its funds to state science and technology program offices for technical assistance. See C. Hill, "The Advanced Technology Program: Opportunities for Enhancement," in Branscomb and Keller, *Investing in Innovation, op. cit.,* p. 165. Positive interactions currently take place between state and federal programs such as the ATP. See Marsha R. B.

within their borders would have a number of advantages. Making awards in parallel with state governments would:

> **a) Increase Certification:** First, parallel awards would increase the certification impact of the ATP award in the local community by raising the firm's profile at the state level. This certification effect can serve to attract private investors by reducing uncertainty concerning the quality and potential commercial applications of the firm's technology.[45]
>
> **b) Leverage Program Funding:** Second, parallel awards might enable the Advanced Technology Program to reduce the size of its base award to individual small business applicants, thereby significantly expanding the reach of the program at no additional cost. In cases where the award size remains constant, the leverage of the award would be significantly and immediately increased by the addition of state funds. Cooperation with state programs would have the additional benefit of aligning the ATP's resources with state efforts, particularly in existing or nascent technological clusters, thereby improving the opportunities for the program and the awardees to reach critical mass.
>
> **c) Expand "Best Practice" Selection:** The ATP has exceptional expertise in the review of technically-sound, commercially-feasible proposals by small independent companies and joint ventures operating with the advantages of large companies (noted above). Care would be required to ensure that an alignment of awards does not compromise the ATP's rigorous selection process. At the same time, ATP cooperation with state agencies would have the advantage of leveraging the ATP's expertise in selection and assessment, contributing to the quality of the state selection process, and the reach of the NIST-based ATP while preserving the current quality of the ATP selection and assessment program.

The Steering Committee*

Schachtel and Maryann P. Feldman, *Reinforcing Interactions Between the Advanced Technology Program and State Technology Programs, Volume 1: A Guide to State Business Assistance Programs for New Technology Creation and Commercialization*, NIST GCR 00-78, April 2000.

[45] Feldman and Kelley, *The Case for Government R&D Additionality, op. cit.*, conclude that "winning an ATP award significantly increases the firm's success in attracting additional funds from other sources for R&D activities." Their findings "provide strong evidence that the ATP award confers a halo effect on winners that makes them more likely to attract other funding when compared to non-winners of the same size…with projects of similar business and technical quality."

* For the Committee membership, see the front matter.

IV

PROCEEDINGS

Welcome

Charles Wessner
National Research Council

Welcoming the participants, Dr. Wessner noted that the meeting is being held under the auspices of the Board on Science, Technology, and Economic Policy (STEP), whose chair is Dale Jorgenson of Harvard University and whose Vice-Chair is William Spencer of SEMATECH. The STEP Board has a broad program of work underway, addressing issues at the intersection of science, technology, trade, and economic policy.[1] The STEP Board's current portfolio of projects includes work on work force needs in information technology, telecommunications innovation and regulation, and medical innovation. Focusing on the impact of new technologies on the U.S. economy, STEP conducted a major, multisector study of the United States' economic resurgence during the 1990s, entitled *U.S. Industry: Restructuring and Renewal*.[2] It also has a major study underway

[1] The STEP Board has a long-standing interest in these topics. For example, in 1995 the Board hosted a major conference on Technology, Wages, and Employment with contributors from many countries, the results of which were integrated into the 1995 OECD ministerial deliberations. In 1995-1996, the Board led a major international cooperative study that resulted in the summary report National Research Council, *Conflict and Cooperation in National Competition for High Technology Industries*, Washington, D.C.: National Academy Press, 1996.

[2] The project reviewed the performance of eleven key manufacturing and service industries, focusing on how they have integrated new technologies as a means of enhancing their current performance and competitive position. The study assessed changing practices in research and innovation, technology adoption, and current operations. An important feature of the analysis is that it illustrates how science and technology are applied in the marketplace, how workers fare as jobs require greater knowledge, and how U.S. firms have responded to their chief competitors in Europe and Asia. This study produced two companion National Research Council volumes: *U.S. Industry in 2000: Studies in Competitive Performance*, and *Securing America's Industrial Strength*, both Washington, D.C.: National Academy Press, 1999.

on *Intellectual Property Rights in a Knowledge-Based Economy*, which is assessing the impact of IPR policies on performance and communication of academic research, mobility of highly trained personnel, and competition and industry structure. This project was launched with a conference in February 2000 entitled "Intellectual Property Rights: How Far Should They Be Extended?"

Today's meeting is the second in a series organized at the request of the National Institute of Standards and Technology (NIST) to fulfill a Senate mandate to examine the operations of the Advanced Technology Program (ATP). As a major government-industry program, the review of the ATP falls under the STEP Board's ongoing analysis of *Government-Industry Partnerships for the Development of New Technologies*, led by Gordon Moore, Chairman Emeritus of Intel.

To review this sometimes-controversial program, the Board has invited an exceptional group of economists and entrepreneurs, as well as the federal officials responsible for the program, to discuss and assess the Advanced Technology Program. Dr. Wessner offered a warm welcome to Alan Balutis, the new Director of ATP, and Cita Furlani, Acting Deputy Director, and expressed special recognition to Rosalie Ruegg, the Director of the Office of Assessment for the ATP, now retiring from federal service after a distinguished career.

The goal of the day's meeting was to take a careful look at the operations of the program, current trends and issues, and in particular, the well-developed assessment program of the ATP, Dr. Wessner said. To open the proceedings, he introduced Clark McFadden, a partner in the Washington law firm, Dewey Ballantine, who has been closely involved with many leading U.S. partnership programs. Because of his exceptional expertise, Mr. McFadden was named to the Steering Committee assembled by the STEP Board for the entire series of reviews of government-industry partnerships for technology development, including this meeting on the ATP.

Introduction to the Symposium

Clark McFadden
Dewey Ballantine

On behalf of Gordon Moore and the rest of the Steering Committee, Mr. McFadden welcomed the group. The STEP Board has chartered the Steering Committee to oversee a series of reviews of *Government-Industry Partnerships for the Development of New Technologies*, a program begun in 1998. Since then the Committee has reviewed several partnership programs in some depth, including generic partnerships such as the Small Business Innovation Research (SBIR) program. One of the main topics of discussion nationally during this time has been the ATP.

The ATP is unique among government research and technology programs in several respects:

- It goes beyond basic research (the traditional government focus), supporting industrial research in "enabling" technologies and encouraging commercialization of those technologies. It is therefore on the leading edge of government-industry relationships.
- It has been intensively studied and assessed. The core competence of the National Institute of Standards and Technology, ATP's parent, is measurement, and the agency has assiduously assessed the outcomes of the program.[3] The U.S. General Accounting Office (GAO) and congressional committees have frequently shone their own spotlights on the program. The Steering Committee, for its part, has profited from this extensive eco-

[3] This volume includes abridged versions of some of the best recent work on this program. For a detailed description, see the Introduction.

nomic analysis in its review of the ATP. The goal today is to bring varied points of view to bear on the program's effectiveness, efficiency, and rationale. These reviews will help the Steering Committee develop better ways to balance the risks, returns, and opportunity costs of other government-industry collaborations.

- Finally, the program is uniquely controversial. Although it began with significant bipartisan support, in the mid-nineties it became more closely associated with the Clinton administration. As a result, it was subject to intense scrutiny. One offshoot of this controversy is that the ATP has developed an exceptional assessment program, which we will hear more about later.

Despite the frequent discussion of the program, an overview of the program's objectives and operations as well as the views of awardees and venture capitalists of its impact has never been undertaken. To provide an overview of the program's goals and operations, the Steering Committee produced an initial report on the ATP, copies of which are available at the meeting.[4] The focus of today's meeting, he said, is assessment.

Outlining the day's agenda, Mr. McFadden reviewed the five panels that will review and discuss aspects of the program.

- Panel I will review the ATP Objective: Addressing the Financing Gap for Enabling Technologies. Moderated by Charlie Trimble of Trimble Navigation, who is also a member of the Steering Committee, this panel will offer the viewpoints of a venture capitalist, the founder of a high-technology start-up company, and a representative of a major high-technology corporation.
- Panel II will review the ATP's Assessment Program. Moderated by David Goldston, Legislative Director for Rep. Sherwood Boehlert (R-NY) this panel includes a summary by Rosalie Ruegg of the work of the assessment office and a critical assessment by two distinguished panelists.
- Panel III, moderated by David Finifter, College of William & Mary, will address some of the recent work on Stimulating R&D Investment.
- Panel IV takes up a major study on Assessing Progress: Case Study Clusters, moderated by David Austin of Resources for the Future.
- Panel V, moderated by Charles Wessner of the National Research Council, assesses the ATP Assessment Program and has the dual objectives of (a) reviewing the ATP's assessment program and suggesting improvements and (b) more generally reviewing the orientation of the ATP program itself and suggesting possible improvements.

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[4] National Research Council, *The Advanced Technology Program: Challenges and Opportunities*, Charles W. Wessner, editor, Washington, D.C.: National Academy Press, 1999.

Panel I: The ATP Objective: Addressing the Financing Gap for Enabling Technologies

INTRODUCTION

Charlie Trimble
Trimble Navigation

Mr. Trimble introduced the first panel by reminding participants that the ATP was originally set up to address the "funding gap" for emerging technologies (that is, the tendency of the private sector to underinvest in research and development). Three panelists, from very different backgrounds and perspectives, would present their views on the program. The panel includes

- Elizabeth Downing, the proprietor of a start-up company that has received government support from several programs, including the ATP;
- David Morgenthaler, a successful venture capitalist, who has not been associated with the program; and
- Kathleen Kingscott of IBM, who will outline why a large company values partnerships programs such as the ATP.

THE VIEW FROM INDUSTRY: A START-UP'S PERSPECTIVE

Elizabeth Downing
3D Technology Laboratories

Elizabeth Downing—President and CEO of 3D Technology Laboratories, a high-technology start-up company—said that her firm had received several SBIR awards and was actively cooperating with the NASA Ames Laboratory. It also had a single-company ATP grant about one and one-half years earlier, and was about halfway through the grant.

Start-ups like hers, she explained, have a hard time finding funds to develop their technologies, because of the high risks. This is true even of so-called enabling technologies, which have the potential for widespread application upon further development, but which carry high technical and financial risks. As a result, private investors generally are not willing to support them adequately.

Enabling technologies are technologies that have significant advantage because they

- show the potential to make radical improvements in some aspect of society;
- tend to be disruptive, by displacing entrenched industries;
- have the potential to create whole new industries; but
- are too immature and risky to interest private investors because of the long time horizon (even successful technologies may require years or decades to become commercially viable and generate profits).

Why should government fund the development of enabling technologies? Because they have the potential for enormous benefits to society as a whole in terms of wealth and other aspects of the quality of life. Yet private investors will not adequately support their development, because profts are too uncertain or too distant or both. The uncertainties may arise from poor scientific understanding, the need for major improvements in materials, or severe manufacturing challenges.

Traditional sources of equity financing, Dr. Downing said, are not always sufficient at this "seed" stage of development. Venture capital, for example, is an excellent source of funding for companies whose technologies are well enough established to be predictable and scalable in the near term. But for companies built on technology that is more speculative, this source of financing has dangers. Venture capitalists, if they are denied a predictable return on their investments after a few years, will often sell the company for the value of the patents and move on to other investments. Many venture capitalists have neither the time nor the background to be ideal partners.

So-called angel capital (from family, friends, or wealthy investors) may have a longer time horizon. But it is extremely scarce.

Corporate investments in technology-based start-ups are often attractive, when there is a genuine mutuality of interest. But large companies may have many motives for investing. They may, for example, take control of the entire company for the sake of only one part of its technology portfolio, and abandon the rest.

Government funding, through programs such as the ATP, helps mitigate these problems for small companies. In particular, it helps the founders of small firms keep control of their technologies and pursue their development.

A Potential Enabling Technology: Crossed-Beam Volumetric Displays

Dr. Downing's company, 3D Technology Laboratories (3DTL), was formed to exploit an invention called crossed-beam volumetric displays (CBDs). The CBD concept produces a true three-dimensional display in a volume of a special active material, by scanning the material's interior with two independently steered laser beams of different wavelenths. The transparent material, when illuminated by two of the beams at once, emits a photon. By controlling the scanning, the material can be made to display a three-dimensional video image.

The technology, if it can be successfully developed, would certainly be an enabling technology. It would offer many advantages over conventional displays, and might be expected to displace two-dimensional displays in applications throughout the economy.

Reducing Technical and Market Risks

Reducing Technical Risks

At the same time, it presents high risks, which would deter any private investor. The technical risks include the following:

- uncertainties about whether it can be scaled up from its current small size;
- questions about the properties of the material; and
- questions about the availability of software to support this novel display.

But all three aspects of technology risks are being reduced through federal funding. 3DTL has used nearly the full range of federal seed funding that is available to a technology company—Small Business Innovation Research grants (phases I and II) from several agencies; an ATP grant; a Defense Advanced Research Projects Agency (DARPA) Broad Area Announcement; and Cooperative Research and Development Agreements (CRADAs), along with federal contracts, to carry out work on scaling, system architecture, and software development. The goal of this work is to develop a working prototype. If successful, this will substantially reduce the technical risks as perceived by private investors.

Reducing Market Risks

Market uncertainties are also great. At this point, it is impossible to estimate the size of the potential market. Early systems will be expensive, so it is important to identify "early adopter" markets, in which cost is less of an object. In addition, significant markets for the software may be available; the company is selling "development time" to customers in the software research community that want to write software.

The company's business goal is to "develop and manufacture versatile engines," with software that can be configured into specific products. It wants to sell directly to various markets, including medical, defense, scientific visualization, and others.

Advantages of ATP for Small Companies

Downing concluded by saying that federal funding programs have made it possible to reduce the technical risks of the technology sharply. Recent technical breakthroughs have allowed the company to move to "limited manufacturing." The company is now at the point at which it is able to look for private sources of capital, including venture capitalists and corporate partnerships.

Of all the federal funding programs that the young company has participated in, she said, the ATP was by far the most useful, because of its large funding commitment, long time duration, and administrative simplicity.

DISCUSSION

Mr. Trimble asked Downing how many employees she had. "Six," she answered, of whom all but one are technologists. Mr. Trimble observed that this suggests the ATP is a very efficient way to deliver money to technologists, involving virtually no overhead.

John Newman of the Council on Competitiveness, asked for the "decision tree" leading her to apply to the ATP program. Downing answered that she had started the company as a graduate student and had begun with SBIR grants which are significantly smaller than an ATP award. An ATP employee at a meeting had suggested that she apply for an ATP grant. She was selected to give an oral defense of the project and ultimately won the award. She added that "It's absolutely the best way to go for a small company with high-risk technology."

THE VENTURE CAPITAL PERSPECTIVE

David Morgenthaler
Morgenthaler Venture Capital

David Morgenthaler, founder of Morgenthaler Venture Capital, said that venture capitalists are probably not as bad as Downing had implied. It is important to understand the nature of the business. Institutional venture capitalists must be accountable to their limited partners. Pension funds, endowments, and others give them money to manage, and they demand in return a positive and fairly predictable internal rate of return. They do not like to wait 10 years (the normal lifespan of our funds) for a return on their money. They will not invest in a company that will pay off in 15 years.

Morgenthaler Ventures is 32 years old, and has a national scope, with offices in Cleveland, Silicon Valley, and Atlanta. It has raised more than $1 billion and has more than $550 million to invest today. Mr. Morgenthaler remarked that he is often asked by local authorities how they can build a dynamic entrepreneurial high-technology economy in the next two years. The answer is that it cannot be done. Many of the nation's older industrial cities lost their entrepreneurial edge at some point and do not have the critical mass of Silicon Valley.

The government has, of course, had a role in the creation of Silicon Valley. An Ohio lawyer once boasted to him, after a couple of drinks, that he had created Silicon Valley.

This was a bold claim, so he asked the lawyer to elaborate. "As a procurement officer at Wright AFB," the man said, "when they were setting up the space program, I was in charge of finding sources for the associated communications technology. I discussed the concept with all of Ohio's industries. They knew nothing about the technology, and were quite complacent about their positions in steel, automobiles, plastics, glass, and so on. In short they were not interested. So I took it to those long-haired hippies in California. And that was the birth of Silicon Valley."

That story, of course, is very much an oversimplification. But those government contracts had a great deal to do with the growth of the electronics industry. And Ohio did not have the entrepreneurial resources to make that leap. This is one of the reasons that my firm decided to go national.

Venture Capital in the United States

Venture capital investments have grown dramatically in the past few years. In 1993 $3.9 billion were raised in the United States. By 1999 the total was $46.6 billion. This does not include buy-out funds, so-called mezzanine funds, funds of funds, or other private equity. Remember that the largest single source of venture capital—dwarfing the share of venture capital firms—is of course the so-called "angel investor," who are relatives, successful business persons, or private investors willing to finance start-ups.

This rapid growth in venture capital suggests that there is plenty of investment money. The question, Mr. Morgenthaler observed, is how to evaluate its risk profile, and whether it can be a satisfactory source of funding for start-up companies with early-state, or immature, technologies.

How Venture Capitalists Evaluate Potential Investments

To elaborate this point, Mr. Morgenthaler described how Morgenthaler screens its opportunities for investment using a simple seven-step checklist, which includes

- the need you are addressing, including the size of the potential market;
- the product or service to fill the need;

- the plan or program to fill the need;
- the people, and their ability to implement the plan;
- financing (the ability of the above to attract funds);
- the exit strategy, that is, the potential for liquidating the investment within 4 to 7 years, such as by going public or selling out to a bigger company; and
- the internal rate of return.

What Stage?

A key question is at what stage in the maturity of a technology should a venture capitalist invest? Maturity is inversely correlated with risk, so we prefer to invest when technical uncertainties are reduced. We like to invest in improving or broadening an existing product line, or applying it in a new application. We are often willing to invest in applying an enabling technology to develop or improve a new product. We are rarely tempted to invest in developing an enabling technology to implement a knowledge principle. We would never invest in the scientific work of discovering a new phenomenon or principle, and we practically never invest in work to prove such a principle.

Sometimes we do invest in fundamental research, but never intentionally. I am on the board of a public company that has invested $140 million in pursuing a Nobel-prize-level science project, which may have a tremendous market at some point, if all of the technical and market uncertainties are reduced. However, this in not a typical investment for us; nor should it be. This has to do with the final item on my list, which is the internal rate of return. In many ways this is the limiting criterion on venture capital investments, because we always have our limited partners looking over our shoulders. If you make someone 10 times his money in three years, that's wonderful. If you do it in five years that's good. If it takes 10 years, it doesn't meet the partners' expectations for internal rate of return, and if it takes 25 years they'll never invest with you again.

The Venture Capital Horse Race

Understanding the appropriate role, and limitations, of the venture capital business is important. In many ways, the venture capital business can be likened to a horse race. In this analogy, the technology in which one has invested is the horse. The management of the company is the jockey. The market is the race. The venture capitalist is the owner and trainer.

The race can have any number of outcomes. The horse may be great, but a poor jockey may fall off, losing the race by default. Or the horse may be inadequate, so that even a great jockey—able to get every ounce of performance out of the horse—will still not win. Or you may have a great horse and a great jockey, but decide to race at the county fair (that is, in the wrong market), winning easily, but capturing a trivial prize.

The ideal situation for a venture capitalist is to have a great horse and a great jockey, and to enter them in the Kentucky Derby (a huge market, in our homely analogy). The stakes here are tremendous, because all of the greatest competitors will be at the starting gate ready to enter in the race. If neither the technology nor the management is world-class, then we have no hope of winning. For example, we were early investors in Apple Computer, which originated the mass-market personal computer. We were worried that, once the market for such things was proven, cheap Asian producers would undercut the market. But we were looking in the wrong direction. Apple management predicted a more direct threat: that IBM, the great 800-pound gorilla of technology, would jump in once the market was proven, and Apple would have to find a niche market to survive. That is what happened.

Generally, when we lose, we can blame it on the jockey. Management failures, according to an internal Morgenthaler survey, account for 60 percent of the failed investments, and technology failures for only 10 percent. To be a successful venture capitalist, one needs both world-class people and world-class ideas.

Creating Better Races with the ATP

Today there is a great deal of venture capital available—by far the most ever. The great opportunities in the Internet and biotechnology have generated great interest among investors. Some of these opportunities are real, and some are illusory. Too many investments have been made in both areas. There are 300 public biotech companies and about 1,000 private ones, all but 50 of which need money. Some of these companies will not succeed. In the Internet your guess is as good as mine, but there, too, some companies will go out of business. Venture capitalists cannot finance all of the companies that need additional finance. As you may know, Internet public financing is starting to experience serious trouble. It is hard to predict, but a prudent investor should foresee consolidation and pain.

Public financing for biotechnology was scarce from 1992 to 1999. We brought a biotech company public in 1991, so we know how hard it was to raise funds. The industry underwent a case of investor mania last year, but that was just a blip on the chart and seems to have collapsed.

For a region to develop a technology-based economy, the ATP program or something like it is vital. You may have fine research universities and other scientific talent, but if you do not have the reserves of management and technical skills to bring those great ideas to market, then high-technology development will go elsewhere.

We need better horses, with better bloodlines, to back. But private venture capitalists cannot be expected to support those early, risky projects. The government can help by financing both more discoveries, through basic research, and more "platform technologies," which lead to new and better products and services. These technologies will be the horse that will attract the better jockeys, to create bigger races.

DISCUSSION

Mr. Trimble asked Mr. Morgenthaler what was the average size of a single venture capital investment. "Three to five million dollars for an early-stage company," he answered, "and we would expect to invest about as much again in the next round."

Mr. Trimble said he had started a company in 1978 to exploit GPS technology. It took six years to secure venture capital and 12 years in all before going public. The early years were supported by angel investors. His experience with the SBIR program agrees with Elizabeth Downing's: the gap in funding between Phase I and Phase II is disruptive and not conducive to growing a company.[5] Programs that provide multiple-year funding directly to small groups of technologists—such as the ATP—are far superior.

LOWERING HURDLE RATES FOR NEW TECHNOLOGIES

Kathleen Kingscott
International Business Machines Corporation

In addition to her experience at IBM, Ms. Kingscott noted that she co-chairs the Coalition for Technology Partnerships, a group of many companies, large and small, with an interest in partnership programs. Her talk was intended, she said, to reflect that broader perspective.

IBM and the Changing Process of Product Development

To put the scale of IBM's research in perspective, Ms. Kingscott reported that IBM spends about $6 billion annually on research and development and has facilities throughout the world, including New York, Austin, Almaden, Beijing, Tokyo, Delhi, Haifa, and Zurich. About 15 percent of the research is considered basic or exploratory. IBM researchers have been awarded two Nobel prizes (for work leading to the important technologies of the scanning tunneling microscope and high-temperature superconductivity). Research has a long tradition at IBM. These investments are designed to create and maintain technology leadership. IBM is, after all, a technology company.

Of course, most of the work is technology development, and IBM is successful in this effort. IBM awarded 2,658 patents in 1998, making it the biggest recipient of patents in the world, with more than twice as many patents as the nearest competitor.

[5] The Department of Defense has successfully addressed this gap with the SBIR Fast Track Initiative to speed awards for companies that can attract outside investment. See National Research Council, *The Small Business Innovation Research Program: A Review of the Department of Defense Fast Track Initiative*, Charles W. Wessner, editor, Washington, D.C.: National Academy Press, 2000.

Partnering is Key

Despite this success, the IBM leadership has recognized that it is not enough to carry out this research by itself. Partnerships are essential. This is because the nature of research has changed dramatically for industry in the past 20 years and collaboration is increasingly vital. We once sent our researchers off to do their work, and when they were done they would throw it over the wall, in the form of some kind of publication for those in the company interested in applying it.

Incremental Improvement

It is no longer possible to rely on that haphazard process. In the 1980s, IBM began to focus on its lack of success in the marketplace despite its predominance in research. Ralph Gomory, who was then head of IBM research and is now President of the Sloan Foundation, began to evolve a new approach, of "incremental improvement," driven by product or manufacturing needs. That approach required closer ties between researchers and the technology developers and engineers, working as teams.

In the 1990s we began to connect that approach more directly with the marketplace, by adding leading customers to our teams. We identified 12 or 13 customer sets and worked with the best in each set—as teams—with each team made up of researchers, engineers, managers, and business developers. For each customer set, we tried to develop the best applications possible.

The researchers themselves, surprisingly, liked the new team approach, because they could see the applications and market significance of their work. They were so enthusiastic that we changed our organization to link all of the different product and technical divisions with the research divisions.

Cooperating with Others

Although IBM is a large and successful company, we never forget that we are engaged in global competition. Product cycles are becoming steadily shorter; at IBM they are now measured in "web years," of 90 days. The pace of innovation is illustrated by the fact that half of IBM's hardware revenues come from new products, that is, products introduced in the past six months. Consequently, there is enormous pressure to bring technology to the marketplace more quickly all the time. It is no longer enough to have the best idea; partnerships are needed to develop new ideas and technologies and to move the product to the marketplace. The marketplace moves so quickly these days that if you don't have access to the best people and best technologies inside and outside your company, you will lose. With the need to draw on outside expertise and acquire new technologies and processes, partnerships are increasingly seen as essential. That is where ATP comes in.

ATP and the Value of Partnerships

Partnerships have value in reducing cost and risk, and providing access to technology. They also make technology transfer—which has been called a "contact sport"—more efficient, by improving communication from person to person.

These partnerships involve three kinds of partners: universities, industry, and government. Universities bring breakthrough ideas and talent; industry brings marketplace experience. Government brings scale and scope, resources, and interesting combinations of technologies. The ATP offers the opportunity to bring all three together.

The program's structure has been examined *ad nauseam*, for the benefit of those who consider it "corporate welfare." It is not corporate welfare. It is a means of developing technologies with real and substantial benefits to society. The tinkering that has taken place over the past decade to assuage these accusations risks the success of the entire program. The program's evaluation criteria and technical milestones are clear. Its processes generally work well. It is competitive, merit-based, and peer-reviewed. IBM has participated in nine ATP projects, and we believe the program works.

The program also has unexpected advantages. For example, one under-appreciated advantage of the ATP is its impact on the quality of students' training. Thoughtful companies and organizations should look to ATP for the chance to work with students. It is a valuable screening and training tool for industry. Students like the ATP because it exposes them to real-life industrial problems and provides hands-on experience with industrial work.

Synergy Between Large and Small Companies

ATP's most important function is as the enabler of new kinds of partnerships. The business partnerships it supports would be hard to find anywhere else. Both small and large companies find the program useful. Small companies like ATP because it brings them into contact with large companies, with technologies, skills, and management systems that are sometimes the best in the world. It allows them to shift from being simply a supplier to these companies to being a full partner in an ongoing relationship. For large companies, the benefits are access to the niche expertise and unique talent of small companies, which complement the broad expertise of a company like IBM.

The Role of Government

Government has an important role in partnership programs. First, it serves as an intermediary, or link, between the private and public research enterprises, which sometimes have little contact. Government research has a better chance of paying off in the marketplace under these conditions.

Second, ATP offers a neutral ground, on which companies can come together to develop what David Morgenthaler earlier this morning called "platform technologies," and others call "enabling technologies." Those precompetitive technologies serve as *de facto* industry standards, which can then be carried into the competitive marketplace by various companies.

ATP also makes possible highly productive relationships. IBM, for example, participated in an ATP joint program working on technology for high-definition television. We would never have been able to work with the broadcast television networks and the other members of the partnership without the ATP. The program partnerships stimulate the diffusion of technology more widely. This kind of precompetitive enabling technology development will not get done by private industry operating alone. The result is greater than the sum of its parts.

Challenges to the ATP

As many of you know, the ATP does face a number of challenges. Perversely, one of the main challenges the program faces is the uncertainty generated by the unstable political environment with regard to funding of ATP. This uncertainty has eroded business's confidence in the ability of the program to sustain its commitments. The volatile ups and downs of the ATP budget make companies think twice before they participate. Industry needs stability and predictability, especially for R&D investments.

The political debate has been not only about the budget total, but also about the program's makeup. For example, some have objected to the participation of large companies. The cost-matching rate for large companies has also been debated in Congress.

To perform its mission, the program needs stability. It needs the stability of multi-year budget commitments, to support the kind of long-term view that is implied by the notion of support for enabling technologies.

Policy Issues for ATP

In addition to the uncertain political environment, ATP faces a number of issues:

- Declining ATP budgets. This narrows the window for applicants, constraining applications.
- How close to the marketplace the program should draw the line in defining technologies as "precompetitive," and therefore suitable for government funding.
- Whether or not to focus programs on particular areas of technology. There is a need to strike a balance between identifying leading technologies on the one hand, and developing an industry consensus on the other.
- Whether large companies should be allowed to participate singly, or only as members of joint ventures.

Lessons Learned

Through its participation in this program, IBM has learned some important lessons about partnerships:

- The formation and maintenance of partnerships presents challenging technical, structural, and cultural problems.
- The structure of a partnership contract is critical. It must define the anticipated business model, and take account of the natural trends of technology. If there is no longer-term market for a technology, development efforts will stop. A market must be kept in sight.
- Partnerships must have mutual advantages and strategic synergy for all partners, including attention to human factors, skills, and cultures. All parties must see a win-win situation in order to produce results.
- Partnerships are agreed by senior executives, but to succeed, they must be reinforced throughout the organization.
- Clear goals and measurements of progress and outcomes are important. When these conditions are in place, the results can be very positive.
- A focus on results is vital. The expected outcome must be precisely specified in terms of who is to do what, when, where, and why.

DISCUSSION

"Venture capitalists tend to focus on particular areas of technology. What impact does that specialization have on start-up companies in other technical areas?" one audience member asked David Morgenthaler. In response, Mr. Morgenthaler responded that the specialization is necessary to develop expertise. One of his partners—a highly successful venture capital investor with long experience—recently tried to invest in an Internet company, but lost to a competitor that had more experience in that specific field. Promising start-ups look for deep experience in their area when they are comparing competing offers from venture capitalists.

Maryellen Kelley of the ATP Assessment Office noted that some have criticized ATP for making multiple awards to the same companies. She asked Kathleen Kingscott how many of IBM's nine ATP grants involved new partners. Ms. Kingscott replied that the company's first two awards were as a single company, but all of the rest have been with joint ventures with a shifting but overlapping set of partners.

A member of the audience asked David Morgenthaler for his view, as a venture capitalist, of how effectively ATP helps small companies move their technologies to the point at which private investors can take over. "Very much so," he answered. "It is an excellent program for developing enabling, or platform, technologies, which can have broad applications but are long-term, risky investments. Venture capitalists are not going to fund these opportunities, because they are at too early a stage of maturity. Government can and should. It should do more than it is doing."

Panel II:
ATP's Assessment Program

INTRODUCTION

David Goldston
Office of Congressman Sherwood Boehlert

David Goldston introduced Rosalie Ruegg, Director of the Economic Assessment Office of the ATP who would provide an overview of the ATP assessment program, and Irwin Feller, to comment on the utility of economic assessment in federal programs such as ATP.

DELIVERING PUBLIC BENEFITS WITH PRIVATE-SECTOR EFFICIENCY THROUGH THE ATP

Rosalie Ruegg[6]
The Advanced Technology Program

In her opening remarks, Ms. Ruegg emphasized that the ATP program is led by private industry and that the cost of its awards is matched by direct industry contributions. "By insisting on cost sharing, we keep the program anchored in the market economy, focused on efficiency and the bottom line. At the same time, the program's selection criteria ensure the funding of highly enabling technologies."

In a more detailed discussion of the ATP's economic assessment methods, she recommended the earlier National Research Council (NRC) report summarizing the STEP Board's first meeting on ATP.

[6] Rosalie Ruegg retired from the Advanced Technology Program in April 2000.

Continuing, she pointed out that the program and its evaluation continue to evolve. The 1990s were a decade of innovation for ATP operations, and it was a decade of program evaluation. Program funding expanded early in the decade, under both the Bush and Clinton administrations—albeit much more rapidly under the latter. Program funding then entered a period of uncertainty and decline.[7]

Large and Small Business, Universities, and Laboratories

From 1990 through 1999, the ATP has co-funded 468 projects, with 1,067 participants and another 1,027 subcontractors. More than half of the projects are led by small businesses. More than 145 universities participate, and more than 20 National Laboratories.[8] Funding of these projects by ATP and industry has totaled about $3 billion, with each contributing about half. These projects have seeded innovations that are leading to broad benefits for the nation.

Direct and Indirect Paths to Impact

ATP cost sharing affects the economy through new technical capabilities that enable new and better ways of doing things, generating productivity gains, new business opportunities, employment benefits, solutions to a wide variety of problems, and, more generally, increases in the nation's standard of living and quality of life. These contributions are achieved by both direct and indirect paths.

Direct Returns

The direct path is particularly significant because it is the path along which the ATP is able specifically to encourage U.S. businesses to accelerate development and use of new technologies. It includes both private returns to companies directly involved in the ATP-funded projects (productivity gains, new business opportunities, and so on) and the benefits to their customers of better products and lower costs. The customers typically realize benefits in excess of what they must pay, and this uncompensated benefit from publicly funded R&D is known as a "market spillover." Private returns and market spillovers comprise part of the social return of the technology developed by a project.

Indirect Returns

The indirect path tends to be slower and less amenable to planning, but is no less important. It involves the take-up of the knowledge generated by a project by

[7] See the Introduction for ATP appropriations.

[8] Through the end of 2000, the ATP funded 522 projects with 1,162 participants and an approximately equal number of subcontractors. Through that time, 176 universities had participated.

others outside the project who have not directly contributed to the investment cost. Even if a project's participating companies fail to commercialize their project's technology—even if David Morgenthaler's jockey falls off the horse, we still have the horse—indirect impacts may nevertheless be realized as the knowledge is acquired and exploited by others. All of the indirect impacts can be considered spillovers from the original R&D.

The complete social return of an ATP project is the net result of the combination of direct- and indirect-path effects—private returns to the company from the project, market-spillover benefits to that company's customers, and a variety of indirect benefits to other companies and to their customers in turn. Assessing these impacts is a challenging task indeed.

Examples of Direct Benefits

The distinction between direct and indirect benefits of ATP projects can be appreciated by considering two examples of completed projects that have been assessed by the ATP.[9]

Illinois Superconductor Corporation. To illustrate the kinds of impacts that occur along the direct path, consider the Illinois Superconductor Corporation of Mt. Prospect, Illinois, founded in 1990 with eight employees. It was awarded a $1.98 million ATP grant in 1992 (matching the grant with its own $1.56 million) to develop a novel high-temperature superconducting thick-film materials technology. The company's target market was to improve signal transmission in cellular phones. The three-year project was successful, and the resulting technology reduces the number of towers needed to cover a given area by 40 percent. The company has made an initial public offering of its shares, built a production plant, and is producing products based on the ATP work. By 1997, when the ATP reviewed it, it had 75 employees. Cell phone users see lower costs, reflecting the lower costs to the phone companies of these higher powered but sparser networks of towers.

Indirect benefits from the wider circulation of knowledge about the project are hard to measure, although the aesthetic benefits of fewer towers are certainly persuasive to many property owners. One measurable indicator is the number of patents that cite earlier patents developed in the course of ATP projects. In the Illinois Superconductor case, we have identified several such patents already.

Aastron Biosciences. Aastron Biosciences, Inc., was a start-up in 1991, when it was funded by the ATP to develop its stem cell expansion technology. This is a new approach to bone marrow transplantation for cancer treatment, which may

[9] William F. Long, *Advanced Technology Program: Performance of Completed Projects (Status Report Number 1),* NIST Special Publication 950-1, March 1999.

also have other significant medical applications. The ATP provided $1.2 million, and the company another $1.5 million, to fund the project.

The new technology—which allows a small amount of stem cells to be removed from a donor and then "grown" in a tabletop apparatus—represents a dramatic improvement over the best alternatives. It reduces the number of visits a donor must make by 75 percent. The benefits to medical staff include its simplicity, as a result of smaller training requirements. For patients, the process is less painful, with fewer side effects and better medical outcomes. The cost per patient treated is lower, as well.

The technology is in clinical trials now. According to recent news, two terminal cancer patients, who needed bone marrow transplantation, were unable to find a suitable donor. Tiny samples of matching stem cells, however, were found in an umbilical donor bank, and the new technology allowed the small samples to be expanded enough to enable treatment for the patients, who otherwise could not have been treated.

In other cases ATP-funded companies have developed their technologies, received patents, published results, and then opted out of their businesses. In other words, there is no impact on the direct path. But the projects may yet have indirect impacts, because others have shown interest in those patents and publications, or researchers involved in the projects have taken their knowledge and skills elsewhere.

The ATP's Multi-component Assessment Program

Evaluation is complex because the paths that the technologies travel are complex. The evaluation tools that we use represent reasonable attempts to get at both direct and indirect impacts. Our current approaches include

- statistical profiling of applicants, projects, participants, and technologies;
- progress tracking of all projects and participants (through a business reporting system and other surveys);
- status reports for all completed projects;
- detailed microeconomic case studies of selected projects and programs;
- econometric and statistical studies of innovation, productivity, and portfolio impacts;
- limited use of macroeconomic analysis for selected projects and special issue studies; and
- development and testing of new assessment models and tools.

Positive Results Overall

These evaluation studies are designed, conducted, and managed by a team of economists on the staff of the ATP's Economic Assessment Office. They are aided in this work by experts from the National Bureau of Economic Research (NBER), a number of university centers with relevant specialties, and consulting universities, institutions, and individuals.

In closing, I would like to review the results of our assessments of the first 50 ATP projects that were completed. A positive feature of the ATP is that we are willing to look at failures as well as successes. Our data shows that

- 72 percent completed all of their research;
- 52 percent published technical results;
- 54 percent were awarded patents;
- 16 percent received prestigious awards from organizations outside the ATP;
- 60 percent had incorporated their technologies in products that were on the market;
- 80 percent either had products on the market or expected them shortly;
- 90 percent had identifiable outputs of either knowledge (representing the indirect path) or products (the direct path);
- 52 percent had both outputs of knowledge and products; and
- about 25 percent were judged by ATP to have strong outlooks—with potential economic impacts of billions of dollars each. About an equal number were considered to have weak outlooks, and the remaining half were assigned medium outlooks.

Terminated Projects

One of the features of the ATP which makes it stand out among federal programs is that it terminates projects that are not working. We have carefully tabulated the reasons for ending 40 projects that have been terminated, of 468 projects funded, as of April 2000. In 44 percent of these cases the companies or joint ventures asked that the projects be terminated because they had changed their strategic goals or their organizational structures, or because the markets or other factors had changed. Four of them (10 percent) cited financial distress; in other words they ran of ATP funds before they met their goals. Another 13 percent of the terminations involved joint ventures that failed to reach agreement, and so did not start their projects. Another fifth of the terminations were caused by lack of technical progress. About 5 percent were due to early success. And 8 percent were canceled by the ATP because they no longer met the ATP criteria (of high risk, for example).

Early Program Results

Thus far, the ATP program shows some encouraging results that are worth reviewing here.

Leapfrog Technologies. First, ATP projects have developed many "leapfrog" technologies: either brand new solutions (37 percent of the identified applications) or dramatic improvements in cost or performance (63 percent).

Platform Technologies. The projects have yielded many rich technology platforms with multiple uses. Many of the technologies have won highly sought after prizes. Most projects have yielded multiple applications of their technology.

Increased Collaboration. The emphasis on collaboration among companies, universities, and non-profit organizations has been strong. Of the 468 projects, 157 (more than one-third) have involved joint ventures. Most of the single applicants have taken advantage of alliances and subcontractors. The ATP involves a rich and productive mixture of large and small companies, universities, national labs, and others.

Accelerated R&D. High-risk R&D has been accelerated by this program; 86 percent of the projects are said to be farther ahead in the R&D cycle than they would be if they had not been funded.

The estimated public benefits of several projects alone exceed the total costs of the ATP program. This estimate is inherently conservative, since it measures only a part of the ATP portfolio of projects and only their directly measurable impacts.

Distinguishing Features of ATP

In concluding her presentation, Ms. Ruegg outlined the characteristics of the ATP that distinguish it from other public and private technology programs:

Innovation with National Benefits

- emphasis on innovation for broad national economic benefit;
- focus on enabling technologies with high spillover potential; and
- goal of overcoming difficult research challenges.

Industry Leadership-Competitive Review

- industry leadership in planning and implementing projects;
- project selection based on technical and economic merit; and
- project selection rigorously competitive, based on peer review.

Collaboration, Follow-through, and Sunset Provisions

- encouragement of company-university-laboratory collaboration;

- positioned after basic science and before product development;
- requirement that projects have well-defined goals, and sunset provisions;
- requirement that selection boards demonstrate the project's need for ATP funding;
- coordination with other public and private funding sources; and
- U.S. companies planning and organizing for technology applications.

Evaluation

The importance the ATP places on the evaluation of impacts and potential impacts at every stage of the process is worth stressing. The ATP's Business Reporting System tracks progress during and after the performance of each project, assessing the project's goals and expected commercial advantage, its strategies for commercialization, and the collaborative activities and experiences of its members. Each project is evaluated also in terms of the effect of ATP on the project's timing, scale, scope, risk level, ability to do long-term R&D, and ability to attract private investment dollars. After the project is finished, the ATP Assessment Office follows up with studies of progress in commercialization and knowledge dissemination, and the identities of customers and competitors.

PERSPECTIVES ON PROGRAM EVALUATION AT THE ADVANCED TECHNOLOGY PROGRAM

Irwin Feller
Pennsylvania State University

Economists, according to Dr. Feller, are said to have an irrational passion for dispassionate reality. This leads them by training and socialization to endorse evaluation and assessment. But a dispassionately rational stance also leads one to dispassionately scrutinize the impact of dispassionate rationality on public policy making, which has often been characterized by passionate irrationality.

Today's comments focus on three aspects of the evaluation of the ATP:

- technical aspects of the evaluation process itself;
- use of the findings of that evaluation within the ATP; and
- use of the findings of evaluation outside of the ATP.

The Evaluation Process

As an economist with an interest in the economics of R&D and in technology transfer in the private and public sectors, I have been involved in recent years in various program evaluations of federal and state technology development programs.

A Favorable Comparison

In the context of the national science and technology initiatives of the past twenty years—including the Bayh-Dole University and Small Business Patent Act of 1980; the creation of cooperative research and development agreements (CRADAs) under the Federal Technology Transfer Act of 1986; various forms of federal and state cooperative university-industry R&D programs; and the Small Business Innovation Research (SBIR) program under the Small Business Innovation Development Act of 1982—ATP's commitment to and technical approach to assessment compares quite favorably.

The ATP's assessment activities

- began early;
- draw on the work of leading scholars in the field;
- address substantive and complex conceptual and empirical issues;
- use multiple methodologies;
- address both obvious and subtle dimensions of impact; and
- are widely disseminated for external review.

Advancing the Art of Assessment

In keeping with its original objectives—funding what we once called "pre-competitive" or "generic" technologies and which are now being called "platform" or "enabling" technologies—the ATP has gone beyond the efforts of other programs that have sought to measure direct benefits by trying to measure indirect or "spillover" benefits. Measuring these impacts is a difficult, if not heroic, task. The ATP's assessment techniques are at the state-of-the-art and in many ways have advanced it.

The ATP's Assessment Program

A Credible Case that the Program Works

What are the impacts of evaluation on the ATP's procedures? The assessment program has provided a credible case that the program works—that it is proceeding according to design and producing measurable economic and technical benefits. The question immediately arises, however, whether the products of the ATP Assessment Office have had impact on the program's operation or on the world outside the ATP—Congress, for example.

How Effectively Does the ATP Use the Results of Evaluation?

Evaluators generally use the terms formative and summative to describe evaluations of a program; the former is directed at improving a program's performance, and the latter at assessing its overall results. Summative evaluations generally are for experimental programs, where decisions must be made about expanding, continuing, or terminating a program. To quote Adam Jaffe, "We know enough about spillover prediction and measurement to improve the ATP's project selection and evaluation of outcomes using more systematic and explicit treatment."[10]

As an outside observer, I do not know, however, if the ATP incorporates findings from its assessments in program activities. I do know, from my work with other programs and agencies, that the record of use is mixed. Sometimes the information is ignored. Sometimes it is rejected for good reason. Sometimes it is ignored or rejected for other than good reason. It would be very useful to ask the researchers who have evaluated the ATP how effectively their work has been used.

Public Dissemination of Findings

One of the desirable traits of the ATP assessment program is that its findings have been widely published. This public airing of findings is in contrast to many other programs which may use evaluations for internal purposes but do not release the results. These internal assessments produce a fugitive literature at best, with no true accountability. Again, the ATP is performing admirably in this respect.

What are the Impacts of the ATP's Evaluation on Outside Decision Makers?

Tolstoy once observed, "Doing good will not make you happy but doing bad will surely make you unhappy." An evaluator's corollary is "A good evaluation showing bad results will surely kill a program, but an evaluation that shows good results may not save the program." One might add that a good evaluation may not kill a bad program.

In discussing the impacts of assessments on the political environment for the ATP, I draw on the work of Paul Hallacher at Penn State.[11] He has contrasted the political histories and current status of the Manufacturing Extension Partnership (MEP) program and the ATP. Each began about the same time, not from grassroots movements, but from policy networks. MEP has since developed a strong political base. While its funding may be questioned in Congress. It has become an accepted part of the federal agenda, while the ATP has not.

Why is This?

What are the differences between the programs that have led to these different outcomes? One major factor is that MEP has involved state matching funds

[10]Adam B. Jaffe, "The importance of 'spillovers' in the policy mission of the Advanced Technology Program," *Journal of Technology Transfer*, 23(2):11-19, 1997.

[11]P. M. Hallacher, *Effects of Policy Subsystem Structure on Policymaking: The Case of the Advanced Technology Program and the Manufacturing Extension Partnership*, University Park, PA: The Pennsylvania State University, 2000.

and therefore greater buy-in from the states. It also has a broader geographical spread. MEP has reliable support in most but not all state capitals. It also partakes of the cachet of small- and medium-sized business and the strong political support this generates. The ATP, by way of contrast, still confronts charges of "corporate welfare."

Institutionalizing the Program: Sprints vs. Marathons

We have heard much about horse races this morning. I'm uncomfortable with these analogies (having never sat on a horse until quite recently). Instead, having done some running, I would liken ATP to a middle-distance runner. Evaluations, though, are often like sprints, which are often done under a tight schedule to meet some congressional or other funding deadline.

But the race is really a marathon. The winner is determined by who tires first—the program's opponents or its proponents. The challenge is to convert ATP—documented impact by documented impact—into a credible, institutionalized part of the federal science and technology apparatus and slowly defuse the ideological objections of its opponents.

The ATP assessment program is a model for other U.S. technology programs. As a dispassionate rationalist, I would like to believe that over time, U.S. policymakers would find these assessments persuasive.

DISCUSSANTS

Mr. Goldston remarked that he was neither a horseman nor a runner but was willing to carry forward the sporting analogies: The congressional approach is to view the race as both a marathon and a relay race—and one in which no one knows what happened in the previous lap. He then introduced Dr. Nicholas Vonortas of George Washington University and Jim Turner of the minority staff of the House Science Committee.

Nicholas Vonortas
George Washington University

In opening his remarks, Dr. Vonortas asked whether "we might have a business model in this room," asking next "Why are such meetings not being broadcast to the real decision makers in Congress?" He noted that he is one of a small group of economists, who as undergraduates in the mid-1970s became interested in technological change. At that time, we suddenly developed an urgent need for new (energy-related) technologies. The available literature was of two kinds. First was mainstream economics, with a few people paying attention to technology.

Second was the literature in development economics, fairly disassociated from mainstream economics, dealing with very important questions related to technology and economic development. The business literature was still disconnected from economics proper and looked down upon by economists.

Then in the 1980s the United States learned that it had a major problem of "competitiveness." With relatively few exceptions, economists in industrialized countries had just started paying attention to questions of technology, shifting comparative advantage, and competitiveness. Their understanding of the field was still very rudimentary. Policy makers relied on this not-very-well-developed literature for guidance on setting up programs such as the ATP.[12] This movement produced a series of significant new laws, such as the National Cooperative Research Act of 1984, which eased antitrust review of cooperative research by reducing civil penalties and raising the standard of proof.

To me the associated policy deliberation sounded simplistic. American policy makers said, "The Japanese are doing it, so we'll do it, too." Some economists were vaguely aware that there was something called "spillovers."

In 1990, I landed a few blocks away from the Academy, at George Washington University, in the Department of Economics and in a graduate program on science and technology policy. That was the first year of ATP funding. Since then both the ATP and I have grown together. The ATP has been bold in its assessment program and has allowed the two literatures of economics and business to merge. Economists now understand a little better the direct and indirect paths that lead to innovations.

Policy makers have also grown more sophisticated—learning, for example, about complex and simple technologies. This progress is important, but it is not enough. As a result of ATP and other work, we know that innovation involves much more than technology. Because of the globalization of our world, we will need more intelligent policy to support high-technology industry.

European policy makers are perhaps more comfortable with programs like ATP. Part of this comfort reflects the fact that European policy makers never relied on the defense spin-off model to the extent Americans did. Also, the European states have a long tradition of support for national champions and "strategic sectors," though definitions of these sectors has changed over time. From an academic perspective, part of this relative comfort can be traced to different academic traditions. Overseas, studies of the economic impact of technology are placed under the heading of "socioeconomic research." Here in the States we consider it much more straightforward economic research, which obviously places certain limitations to the arguments one can use. Needless to say, we are also aware that quality of life is what is really at stake.

[12] A summary of these programs can be found in the Introduction to this volume.

James Turner
House Science Committee

Mr. Turner opened his remarks with a point of comparison. The ATP, compared with other federal technology programs, is unquestionably far ahead of the pack in its use of program evaluation. In fact, other programs are beginning to apply some of the ATP techniques. At the same time, the program remains in an unstable budgetary position, and always seems to be threatened with extinction. The many GAO reports on the ATP have been very influential in this debate.[13] The purported, but often unexamined, virtues of small business have also held sway over many of those in Congress who authorize funds for ATP. This has led to some of the tinkering with the program's funding, structure, and goals, creating the uncertainty about which IBM's Kathleen Kingscott and others have complained today.

The first hearings in the series that led to the ATP was on April 28, 1987. The hearings were remarkably bipartisan, largely, perhaps, because of the sense of a common adversary in Japan. Sherwood Fawcett, CEO of Battelle Memorial Institute, appeared, explaining how xerography (based on a 1938 process patented by Battelle Memorial Institute) almost died over the decades before it was successfully commercialized. The committee discussed the need for patient capital in such cases.

Rosalie Ruegg's presentation was heartening to him for many reasons. One of them is the fact that she stressed the cancellation of projects that do not work out. If a program makes multi-year funding awards, it should not let projects that are clearly failures go on simply because they were once funded. Turner said that he did not know whether 40 projects terminated out of 468 is the right number but that he believed that 30 would be too few.

Turner was also struck by Dr. Feller's comparison of the political context of MEP and ATP. Both programs were founded under the same statute, the 1988 Omnibus Trade and Competitiveness Act. MEP was designed to have a strong base in each of the 50 states, and therefore quickly became politically invulnerable. The ATP has never enjoyed that deep and broad support, perhaps because the program, despite its merits, has not had the resources to aid companies in a large number of Congressional districts.

QUESTIONS FROM THE AUDIENCE

Lewis Branscomb endorsed Dr. Feller's maxim, "A good evaluation showing bad results will surely kill a program, but an evaluation that shows good results may not save the program." Conversely, he added, if a program is

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[13] See Box F, "GAO Reviews of the ATP" in the Introduction.

politically strong, it does not matter whether you do the evaluations at all. This suggests, he said, that evaluation is largely irrelevant to the political support a program may have. We tend to think of evaluation as measuring program performance (the functional goals specified in the law). The federal agencies that are charged with carrying out the law tend to watch the legislative process, and then—assuming that the political phase is over—carry on with administering the program. Political evaluation as well as economic evaluation is needed. Few federal agencies practice intellectually sophisticated political evaluation.

The Political Impact of Project Termination

These issues go right to the heart of the assessment process, and we should continue discussing them, said Dr. Wessner. What, he asked, is the political impact when a program does what is almost never done, that is, admit failure and identify the projects that do not work?

David Goldston agreed that ATP is nearly unique in this respect. He found this a positive feature of the program, so long as the failure rate is substantially below 100 percent. On the other hand, he was disturbed by ATP's data, presented by Rosalie Ruegg, suggesting that 13 percent of the terminations involved joint ventures that failed to reach agreement and did not start their projects. The key point to remember is that failures are inevitable, and we should be aware of that likelihood and shut projects down when necessary.

The other fundamental point, Mr. Goldston observed, is whether the projects would have been done anyway without federal money, and more generally whether there are other more productive uses of federal money. These questions have been addressed by the ATP's assessment program, but they remain at the crux of one of the difficult—perhaps insoluble—political questions about the ATP.[14]

High Risk Means Some Failure

If ATP had a 100-percent success rate, said Jim Turner, it would be evidence that the program is not selecting risky enough technology projects. One of the rationales for the ATP is that it is a high-risk program, which tackles projects that would not be done by private investors. The termination rate (about 8.5 percent of projects) is evidence that substantial risks are being undertaken. The statistic that should give you pause, if you worry that the private sector would undertake these projects anyway, is the 2 percent of projects that were terminated because they succeeded ahead of schedule. That would raise the question of whether the

[14] Dr. Feldman's research addresses this point and provides an empirical response to the question of whether the projects would have been done without ATP funding in the negative. She finds the projects generally would not be carried out in the absence of ATP funding. See her paper in this volume.

projects are not risky enough, and whether ATP is skimming the cream of investments that would be more appropriately made by the private sector.

Incorporating Evaluation Results

Rosalie Ruegg rose to clarify several points, in particular the observations about the project termination statistics:

- the two projects terminated because they succeeded earlier were cases in which the teams found better ways to get to the projects' goals; and
- ATP funds were never released to the two joint ventures that were terminated because they failed to reach agreement.

Taking up Dr. Feller's question about whether the ATP uses its evaluation results to refine the program's selection criteria and its other operations, Ms. Ruegg said the answer to that question is that the ATP devotes a great deal of attention to feeding its evaluation results back into the selection process. Three economists from the evaluation staff, for example, provided training to the FY2000 selection boards, drawing specifically on evaluation results for their material. As more evaluation results are accumulated, this interaction becomes richer and its impact on the selection process greater.

Even project failures can have successful elements, she stressed, because they result in additions to the knowledge base. The "indirect path" may mean that other companies carry certain aspects of a project forward into the market. Many of the terminated projects, for example, had patenting activity before they ended, and evaluators can often discern signs of knowledge from those patents being exploited by others.

Jim Turner observed that another indirect impact of the projects was its benefits for NIST. The ATP helps keep the agency on the cutting edge of technology and reinforces its ability to perform its mission.

Panel III: Stimulating R&D Investment

INTRODUCTION

David Finifter
College of William & Mary

David Finifter, Director of the Thomas Jefferson Program for Public Policy at the College of William and Mary, said he had worked on evaluation of industry technology programs, particularly SBIR. Today's proceedings make it clear that the ATP has advanced the art of program evaluation to an encouraging degree. As a case in point, he introduced Maryann Feldman of Johns Hopkins University, who presented an assessment of the added value of ATP awards.

ASSESSING THE ATP: HALO EFFECTS AND ADDED VALUE

Maryann Feldman
Johns Hopkins University

Dr. Feldman began by urging that we should reconsider government R&D programs. The literature generally treats such programs as procurement programs, and this approach does not apply neatly to the ATP.[15] The literature generally treats

[15] See Paul A. David, Bronwyn H. Hall, and Andrew A. Toole, "Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence," *Research Policy*, 29(4-5):497-529, 2000. See also T. J. Klette, J. Møen, and Z. Grileches, "Do Subsidies to Commercial R&D Reduce Market Failures? Microeconomic Evaluation Studies," *Research Policy* 29(4-5):471-495, 2000.

government as the main customer or as having regulatory power to approve technology use. It treats the phenomenon of government spending "crowding out" private spending by analyzing programs that mainly address government needs.[16] The literature has also looked at subsidies for R&D through tax incentives.[17]

These approaches may be adequate for most of the research programs of the Department of Defense, the Department of Energy, or the Department of Health and Human Services.

None of them is satisfactory in assessing the ATP. In this program the government is more of a partner than a customer, and there are strong incentives to cooperate, share information, and undertake early-stage R&D.

The ATP has the following critical characteristics that differentiate it from the other government R&D programs:

- a focus on developing the economic benefit of early stage, high-risk, enabling innovative civilian technologies;
- an emphasis on the formation of partnerships and consortia;
- a rigorous, competitive selection process with an independent evaluation of the project's technical merit, commercial worthiness, and potential for broad-based economic benefits; and
- debriefings for those who apply but are not selected.

To learn about the impacts of these differences on ATP applicants, Dr. Feldman surveyed the 1998 applicants (both winners and non-winners), seeking answers to two questions:

- Does the ATP application process reward risky, broad-based research projects?
- Does the ATP award encourage subsequent investment by private investors?

The short answer to both of these questions is "yes." This finding is supported by a substantial research project involving a survey of 240 companies, including winners and non-winners.

The 1998 ATP Competition

In the 1998 competition, 502 proposals were submitted, involving 822 organizations. Of these, 79 proposals (about 16 percent), representing 168 participating organizations, were selected for awards. Joint ventures accounted for 27 of the awards, with 116 member organizations in all. There were 52 single-company awards.

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[16] See D. Guellec and B. von Pottelsbughe, "The Impact of Public R&D Expenditures in Business R&D," paper presented to NBER Summer Institute, July 2000.

[17] See Bronwyn H. Hall and J. van Reenen, "How Effective are Fiscal Incentives for R&D? A New Review of the Evidence," *Research Policy*, 29(4-5):449-469, 2000.

The survey, in 1999, attempted to contact all awardees and unsuccessful applicants. The overall response rate of 60 percent was achieved (81 percent of the firms with awards and 50 percent of unsuccessful applicants), for a total sample size of 241. For each participant in the survey, Dr. Feldman said she and her colleagues matched the responses with ATP's technical and business/economic assessments of proposal quality.

Survey Results

When asked, "Was the ATP review and selection process fair?" 81 percent of the sample, that is, 95 percent of the awardees and, surprisingly, 67 percent of the non-winners answered "Yes." This result is encouraging.

When asked "Do you plan to apply to ATP in the future?" again more than two-thirds of the respondents answered in the affirmative (Table 1).

Does the ATP Application Process Provide Value to Applicants that do not Receive Awards?

The ATP program is intended to help unsuccessful applicants by providing information on proposal deficiencies and selection criteria. Unsuccessful applications may request debriefings by the technical and business specialists who serve on review boards. Our survey found that 82 percent of the non-winners in 1998 requested and received debriefing; of these, 73 percent found that feedback beneficial.

Does the ATP Encourage Wider Collaboration?

The ATP is intended to encourage collaboration. To test this claim, we asked all participants whether they had partners and, if so, whether their partners were new partners or entities with which they had previously collaborated. The responses suggest that half of the applicants were collaborating for the first time with their most important partners (Table 2).

TABLE 1 Participant's Intentions to Apply for Future ATP Grants by Award Status

Plan To Apply in the Future?	Percentage, by Award Status		
	Awardees	Non-Awardees	All Applicants
Definitely/Very likely	82	59	70
Undecided	15	12	13
Not very likely/Definitely not	4	29	17

TABLE 2 Applicants' Tendency to Collaborate with New Partners

Collaboration Status	Percentage, by Award Status		
	Awardees	Non-Winners	All Applicants
Have research partners for this project	83	80	82
First-time collaboration with most important partner	59	43	50

Does the ATP Reward High-Risk, Enabling Technologies?

The survey found evidence suggesting that the ATP awards tend to support risky research projects addressing enabling technologies. Awardees were more likely than non-winners to propose R&D projects that were new to their firms. They were also more likely to collaborate with new partners. They tended to express much greater willingness to share research results with other firms, and to have broader, stronger linkages to other businesses. Companies that are well connected with other companies generate greater knowledge spillovers.

Other Findings

The survey found no significant differences between winners and non-winners that would be correlated with prior experience and success with the ATP. Nor did the effort spent on preparing proposals differ significant between the two groups. On average the companies spent about $20,000 on their proposals, with no significant difference between winners and non-winners. Applicants do seem to be more likely to win if their proposals are in certain technical areas, notably biotechnology and electronics.

To What Extent Did Non-Winners Continue to Pursue the Technologies Proposed to the ATP?

When asked one year after the results of the 1998 competition were announced, more than 60 percent of them had not pursued the project further (Table 3). In

TABLE 3 Tendency of Non-winners to Pursue the Proposed Technologies

Extent of Follow-Up Activity	Percentage
Did not proceed with the project at all	61.4
Began project on a much smaller scale	16.4
Began project on a somewhat smaller scale	11.7
Began project at about the same scale as proposed to ATP	5.3
Began project at somewhat larger scale	2.9
Began project on a much larger scale	0.6
Refused to answer, or don't know	1.8

fact, 49 of the companies surveyed had either gone out of business (23 companies) or the proposed principal investigators had left (26 companies). This finding tends to confirms the riskiness of the projects proposed, since private investors could not be found. About 40 percent continued the project at the same or smaller scale, and about 4 percent pursued it at a larger or much larger scale (i.e., ultimately securing venture capital funding).

Of those non-winning firms that survived, about 40 percent were still working on the project with the same partners (Table 4).

Also of interest is the companies' willingness to seek other funding sources and their success in obtaining it. Here there is a significant difference between winners and non-winners. Nearly half of non-winners applied for funding from other sources, and only 25 percent of the winners. Also telling is the success rate of these applications; nearly three-fourths of the winners were successful, but only one-third of the non-winners.

Awards Serve as Quality Signals

This difference in success rates suggests that ATP awards are signals of quality for private investors and other funding sources. To test this suggestion, we asked companies about the sources of funding to which they applied. Some 39 percent of them had applied to venture capital investors, and 26 percent of these investments were contingent on funding from ATP. State and local programs (to which 39 percent of companies had applied) were even more inclined to make funding contingent on ATP grants (43 percent of the cases). About two-thirds of the companies had applied for funds from other sources, but only 19 percent of these applications had been contingent on ATP funding.

Influences On the Firm's Ability to Attract Financing From Non-ATP Sources for its Technologies

Using multiple regression analysis, my colleagues and I sought to identify the qualities that led to success in seeking funding from other sources. We tested four characteristics:

- firm-specific characteristics, such as the size and age of the entity;
- linkages to universities and other types of organizations;
- the technology field; and, most importantly,

TABLE 4 Continuing R&D Collaborations by Surviving Non-winners

Extent of Continuing Collaboration with Partners	Percentage
No longer working with any research partner	32
Still collaborating on R&D project proposed to ATP	40
Working together on other activities	28

- the extent to which ATP funding itself serves as a certification of quality and commercial value for a technology.

The preliminary results of this analysis confirm the certification effect of the awards and the positive impact of close ties to universities, specifically:

- ATP funding significantly increases the likelihood of attracting additional external funding—and also increases the amount of that funding; and
- close ties to other organizations was also significantly associated with the ability to attract additional funding.

Overview of Results

The results of this study suggest that, as intended, ATP promotes new collaboration among awardee firms and partnerships with universities and government research institutions. Awardee companies express greater willingness than non-winners to share research results with other firms; this reinforces the pre-competitive nature of the selected projects.

Reflecting the program's goals, our analysis shows that

- ATP winners have higher quality technologies and stronger business plans with greater potential economic impacts;
- ATP winners are far more willing to share information on the results of their research;
- ATP winners take greater risks, starting entirely new R&D inquiries with new partners; and
- underscoring the importance of the awards and the high-risk nature of the technologies, most non-winners do not pursue the ATP proposed technologies by themselves.

CHEAP GAS? JOINT VENTURES AND FUEL-EFFICIENCY

Mark A. Ehlen
National Institute of Standards and Technology

Dr. Ehlen introduced himself as an engineer and economist in the Office of Applied Economics, part of the NIST Building and Fire Research Laboratory. His office had been commissioned by ATP to perform an economic analysis of the ATP Flow-Control Machining project, a joint venture lead by Extrude Hone, a small manufacturing-process developer in Pennsylvania.

In his presentation, he said he would first outline the structure of the joint venture, discuss the process technologies developed, and then review the results from the economic analysis of the technologies as used in their first application, in the automotive industry.

A University-Industry Joint Venture

The Flow-Control Machining project is a good example of a vertically integrated joint venture containing the research and business components necessary to both develop a new enabling technology and embody it in a real product, namely a car. The joint venture ran from 1995 to 1999; the analysis began in 1998 and was therefore assessing the potential economic impact of a technology that had yet to be applied.

The joint venture was led by Extrude Hone, a small machine tool company located near Pittsburgh, PA. It built the joint venture by first teaming with the University of Pittsburgh and the University of Nebraska, for technical expertise. It then called on two end-users, the Ford Motor Company and General Motors. Finally, it assembled an informal group of advisors, consisting of experts in materials, casting, and engine design. The joint venture's application to ATP was selected for an award of $3.9 million, matched by $4 million from members of the joint venture.

Technologies

Flow-control machining is a novel approach to machining complex metal parts to shapes that are smoother and perform more precisely. The technology has potentially wide application in the automotive, aerospace, and medical industries. A single application was chosen as a target for the project: the intake manifolds and intake ports of automobile engines. (See Larry Rhoades' presentation below.)

In the air-handling parts of engines, precise flow and volume control can pay great dividends in fuel efficiency and power, for example, by reducing turbulence and imbalances in intake air. The joint venture was to develop automated techniques, using neural-network feedback systems and acoustic emissions detection, for machining metal parts to precise levels of flow and volume, thereby significantly increasing overall performance of a machine such as an automobile engine.

Economic Analysis

The economic assessment began with a careful market analysis of automobile supply and demand, market competition, and the EPA's fuel-efficiency regulations. It was evident from this analysis that the most likely initial application of the flow-control machining technology was among the automakers' largest and lowest fuel-economy vehicles, which yield the manufacturers high profits. Current production of these vehicles is limited by Corporate Average Fuel Economy (CAFE) standards, which mandate minimum levels of fleet fuel economy. Higher fuel efficiency in these models would allow further production of these profitable vehicles while satisfying CAFE, making implementation very attractive to manufacturers.

To estimate the extent and the duration of market penetration, we reviewed the history of the penetration of other fuel-efficiency technologies, illustrated in Figure 1. Fuel injection, for example, achieved 80 percent market share over a period of 15 years; front-wheel drive has had a similar history of penetration. The three-valve engine, on the other hand, lasted for only about 7 years, with a maximum penetration of 5 percent, and eventually dwindled in use.

We concluded that there is an initial five-year period during which a fuel-efficiency technology has a high chance of being adopted. After that, adoption is much less certain. We modeled then two scenarios: an initial five-year adoption on the equivalent of a single production line; and a longer-term adoption, like that of front-wheel drive or fuel injection.

In both scenarios we assumed that the new flow-machining technologies would improve automobile fuel efficiency by 6 percent (as estimated by Extrude Hone). In the first (short-term) scenario, the direct benefit to Extrude Hone is about $1.6 million. The benefits to the economy are much greater: gross domestic product (GDP) expands by an estimated $143 million, an additional 3,600 jobs

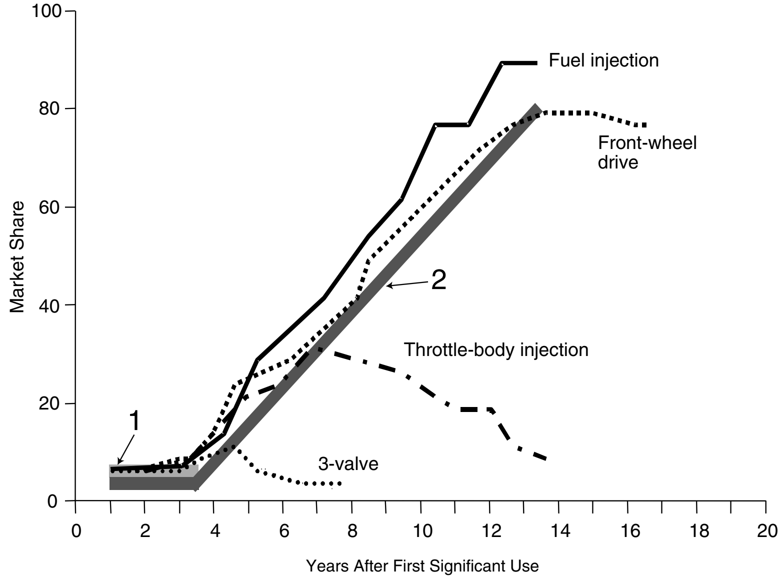


FIGURE 1 Market penetration of earlier automotive technologies that improve fuel-efficiency

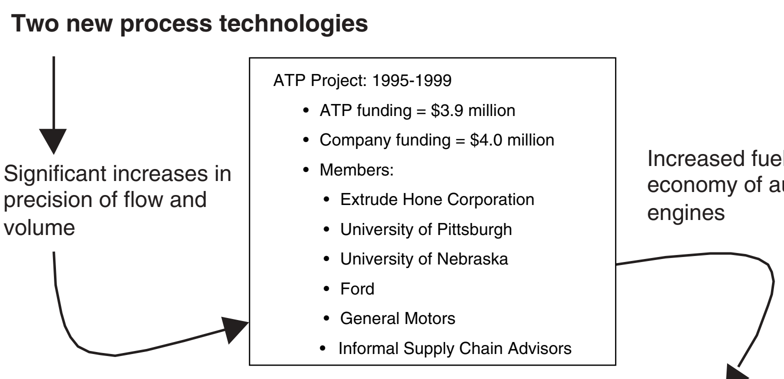
are created, and $34 million annually in additional tax income revenues are generated.

Assuming that penetration followed the second (longer-term) trajectory, we estimate that the technologies increase GDP by $1.9 billion, create 58,000 new jobs, and add $0.5 billion in tax revenues. Figure 2 outlines the simulated economic impacts of these two scenarios.

These results were found to be conservative to variations in the following external conditions:

- increases in CAFE requirements;
- changes in consumer preference;
- the existence of competing technologies;
- the realized fuel efficiency gains; and
- other broad applications of the two processes.

Interestingly enough, the market penetration does not depend much on rising gasoline prices; of late, car buyers are more concerned about safety and options than about fuel economy.



Impacts on Auto Industry	**Near-Term Estimate**	**Longer-Term Estimate**
Extrude Hone Corporation	$1.6 million/year	
Industry GDP	$142 million/year	$1.9 billion/year
Industry Employment		
Manufacturing	1,800	29,000
Non-manufacturing	(1,800)	(29,000)
Income Tax Revenues	$34 million / year	$0.5 billion/year

FIGURE 2 Forecast economic impacts of short- and long-term market penetrations of flow-control machining

DESIGN FREEDOMS AND ENHANCED VALUE

Larry Rhoades
Extrude Hone Corporation

Extrude Hone Corporation, said Larry Rhoades, is dedicated to developing and implementing advanced manufacturing processes, including non-traditional machining, finishing, and measurement technologies. We view our mission as efficiently moving research onto the factory floor.

The company has 250 employees worldwide, including 170 at its headquarters in Irwin, Pennsylvania, but we have an eye on world markets, since 55 percent of our sales are made overseas. The scope of our technology encompasses the following areas:

- abrasive flow machining, finishing, and deburring;
- electrochemical machining and deburring;
- surface-edge dimensional measurement;
- ultrasonic machining and orbital polishing; and
- solid free-form manufacturing of metal tools and parts.

Each of the processes enhances the performance of a product; it does not simply make it cheaper. Our goal in developing manufacturing processes is to achieve processes that offer greater design freedoms to manufacturers. We serve an extraordinarily broad range of industrial demands, including dies and molds; aerospace engine components; ultra-pure devices for medical, pharmaceutical, food, and semiconductor applications; diesel engine manufacturing; and automotive manufacturing in general.

The automotive manufacturing market represents about one-third of the market for machine tools in this country, but it is a challenging market to those who would introduce process innovations. It is an industry that does not welcome risk.

Consequently, we generally begin by introducing new technology in the aerospace market, which has traditionally been led by military aircraft turbine engines. Their advanced materials are nearly un-machinable, their designs characteristics are nearly non-negotiable, and they are manufactured using very strange processes. For these reasons, that industry tolerates processes that do not quite "work." It is a nurturing environment, in which a process can be refined and improved and perfected, and eventually—once it is perfect—make the transition to the diesel engine market and then to the broader automotive industry.

Ordinarily the transition from the complex geometries and difficult materials of the aerospace industry to the high-volume production of the automobile industry takes 10 to 20 years—or, in "Dot.com" parlance, 40 to 80 Web years. With our ATP project we made the transition from high-performance, low-volume aerospace to the high-volume production of the automotive industry in one giant leap.

This transition, in fact, might not have been possible at all if it had not been for the ATP project, because the automobile industry is normally so difficult to penetrate.

Two ATP Projects

The common theme of all our activities is to widen the design freedoms of manufacturers. The theme is illustrated by the technologies pursued in our two ATP projects:

- Flow-Control Machining, and
- 3D Printing.

Flow-Control Machining

The technology we developed in our first ATP project involves passing an abrasive putty compound through the internal passages of an ordinary cast and machined part, which enables us to control the shape and smoothness of areas of the part that normally cannot be reached with ordinary machine tools. The project tackled two critical features of internal combustion engines.

- Smoothing the surfaces of the intake ports, through which the air enters the cylinder head. By lowering turbulence within the flow passage, this makes the engine breathe more easily, and increases both the mass and entry velocity of the air drawn into the combustion chamber, providing a more complete and leaner fuel/air mixture and, consequently, more efficient and cleaner combustion.
- Second, precisely "sizing" the volume of the combustion chamber cavities on the cylinder heads to provide the optimal compression ratio. This offers about 2-3 percent higher fuel efficiency, as well as higher power.

With these two effects, it would be possible to custom-tune standard engines for particular performance goals and conditions of use (such as climate). Automobile manufacturers would have more flexibility if they could tune each car to its environment.

The initial application was a Ford 2.5 liter engine used in the SVT version of the Ford Contour. We moved from there to the engine that powers the Cobra—the premier Ford label. We also will have a Chrysler product out within six months. The industry's approval of this process, including Ford's participation (and Ford's acceptance of any warranty implications) was a strong signal of the industry's approval. Through the ATP project we were able to prove the technology, scale it up, and insert it into the industry in a single step. The challenge now is to install the process throughout the industry.

3D Printing Process
for Direct Fabrication of Automotive Tooling

The second project involves a new process of component fabrication from metal powder, which is assembled, layer by layer—almost particle by particle—into complex part configurations, which can be sent and received over the Internet. The technology is based on that of an inkjet printer, and the process, invented at MIT, is akin to rapid prototyping processes. Instead of making prototypes, however, it makes actual functional parts.

In building up the parts in this way, the materials used in different areas of the component can be varied in porosity, density, and other characteristics. We can currently make parts at a speed of a quarter of a liter per hour. With the ATP funded effort, this will be about 20 times that speed. Custom-made parts, formed at distributed locations, opens the possibility of installing a machine in your neighborhood, or even in your basement that could make specific parts as needed for your car appliance or even that mantle clock that's been in the family for six generations. The logistics of distribution can be revolutionized. Materials can be recycled or otherwise controlled at the point of assembly.

For manufactures, the design freedoms offered by this approach include

- selective porosity;
- reduced assembly;
- new materials;
- electronic information exchange; and
- intricately complex geometries, which allows designers, for example, to create internal conformal cooling lines in metal tooling to reduce molding cycle times.

In addition, this technique reduces time, cuts waste, and allows more flexible scheduling. This four-year project involves a joint venture headed by Extrude Hone, with General Motors as an unfunded partner and MIT and Cobra Tool as subcontractors.

Moving Beyond the Traditional R&D Strategy

Both these projects permit manufacturers to enhance the value of their products. This reverses the traditional industrial R&D strategy, of translating customers' desires and government regulations into product designs, which are then given to manufacturing engineers to devise appropriate production processes. Markets are moving too fast for that now. These ATP awards are examples of a new model, which involves designing processes and products together, through a process of mutual feedback.

It is important to keep in mind that the entire U.S. machine tool industry, in aggregate, would equal in annual revenues less than the smallest of the Fortune

200 companies. Yet these small companies shoulder the responsibility for R&D and innovation that drives a sizable part of the world's economy. Machine tool builders are the source of most process innovation in manufacturing. These innovations have tremendous value to our customers, and to consumers everywhere. Yet, as Mark Ehlen explained earlier, only a tiny percentage of the value created through these innovations is returned to the machine tool companies that developed them. Filling that gap—between the huge spillover benefits of innovation in production processes and the tiny returns to those who make the investments—offers great economic leverage to a program like the ATP.

QUESTIONS FROM THE AUDIENCE

Bernard Gelb of the Congressional Research Service asked Maryann Feldman about her statistical controls in the survey she had reported on. The 50 percent response rate for the companies not selected for ATP grants is quite good, but was there any control for self-selection in comparing responses of winners and non-winners in as much as the firms themselves choose whether to respond?

She answered that there are no obvious signs of bias. For example, no clearly skewed pattern of geographical distribution or technologies addressed appears in the two groups. Furthermore, she suspected, unsuccessful proponents would seem to have particular incentives to criticize the program. (Many, in fact, did take the opportunity to offer critiques). But the researchers have no way to control statistically for such possible bias, so it remains an open question.

Dr. Wessner asked Dr. Feldman to elaborate on criticisms offered by the respondents. She answered that although most participants (73 percent) had found the debriefings helpful, and 29 percent of the non-winners said that they would not consider ever applying again.

One participant recounted an early proposal in NSF to evaluate the SBIR selection process by surveying the winners and comparing their responses to those of the runners-up. It foundered on the unwillingness of agencies' overtaxed selection personnel to identify the runners-up.

Among the private sector applicants there is a similar problem, Dr. Feldman said. Many of the successful applicants failed to respond to her survey because they were too busy working on their technologies.

Bill Long of Performance Research asked Larry Rhoades whether it is typical of his industry to capture only 1 percent of the total value created by a new innovation, as documented by Mark Ehlen's study of the Flow Control Machining project.

"Our ability to harness the value created in a manufacturing process is constrained," Mr. Rhoades said. Because the typical company is small compared with its major customers, its negotiating leverage is limited. Second, these companies need dozens of specific applications to make a new process pay for itself, and distributing the costs across these many customers is difficult. One way to improve the return, by as much as an order of magnitude, is to provide production services with these new processes as well as equipment. The auto industry, for example, is not good at installing and refining new processes, and small, nimble companies can offer a valued service in that way. On the other hand, he observed, we have both a responsibility and an incentive to pursue widespread application. And to create the greatest possible benefit to the U.S. economy.

Bill Long suggested to Maryann Feldman that they should consider surveying companies that have not applied to ATP. Doing so would strengthen the case for concluding that ATP projects fund technologies that would not be able to attract private capital—that the program does not compete with private funding sources.

We have considered that strongly, Dr. Feldman replied, but we have no way to construct such a sample. We have data on our companies' funding histories before applying to ATP but not on companies that have never applied. In this connection, Dr. Wessner suggested that David Morgenthaler's observations be taken into account. As a past president of the National Venture Capital Association and a leading figure in that industry, his view that there is little, if any, overlap should be kept in mind.

Lewis Branscomb suggested that Dr. Feldman's team approach venture capital firms for information on firms that they fund. The funding histories of those companies might be compared with reference to their ATP participation and other relevant factors.

Yes, said Dr. Feldman, but such a retrospective study—relying as it must on people's recollections—would introduce its own biases. Still, some statistical approach to the non-participating companies would be valuable.

Panel IV:
Assessing Progress: Case Study Cluster

INTRODUCTION

David Austin
Resources for the Future

The coming session, Dr. Austin said, would present a series of studies on a variety of topics. The first would be a presentation by David Ayares on a project designed to address the pressing national need for organ transplants. The second reviews case study methodologies for evaluations, and the third focuses on economic returns in medical technologies.

As background information, he called attention to three recent ATP studies assessing the ATP program:

- *Estimating Future Consumer Benefits from ATP-Funded Innovation: The Case of Digital Data Storage*[18]
- *Managing Technical Risk: Understanding Private Sector Decision Making on Early Stage Technology-based Projects*[19]
- *Performance of Completed Projects: Status Report Number 1*[20]

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[18] D. Austin and M. Macauley, *Estimating Future Consumer Benefits from ATP-funded Innovation: The Case of Digital Data Storage*, NIST GCR 00790, April 2000.

[19] L. M. Branscomb, K. P. Morse, and M. J. Roberts, *Managing Technical Risk: Understanding Private Sector Decision Making on Early Stage Technology-based Projects*, NIST GCR 00787, April 2000.

[20] W. F. Long, *Advanced Technology Program, op. cit.*

Each of these studies has value in its own right. Collectively, they underscore the quality and scope of the analysis referred to by Professor Feller and Dr. Wessner.

THE FIVE LITTLE PIGS: A TALE OF XENO-ORGAN TRANSPLANT

David Ayares
PPL Therapeutics, Inc.

PPL Therapeutics, said Mr. Ayares, is new to the ATP, having received its first grant only five months previously. The company—a U.S. subsidiary of a foreign company—is working to develop the technology of transgenic animals, based on earlier work at the Roslyn Institute in Scotland. At its Blacksburg, Virginia, facility it has two technology focuses:

- transgenic production, that is, transplanting genes for various human proteins into farm animals, to produce pharmaceutically and nutritionally important proteins in their milk; and
- xenotransplantation, that is, genetically modifying pigs so as to produce cells and organs suitable for transplantation into humans without spurring immune rejection of the grafts.

PPL's lead product is alpha-1-antitrypsin (AAT), a compound used in treating cystic fibrosis and other diseases. It is produced in the milk of sheep at very high rates, making the process much cheaper than the traditional recombinant methods. The company is also working on recombinant methods for producing a variety of other human proteins for therapeutic and nutritional purposes. It has several products in clinical trials. The company, PPL Therapeutics, became widely known a few years ago for producing Dolly, the cloned sheep. Cloning of animals is a necessary step in order to multiply quickly the amounts of the various pharmaceutical products that the original transgenic animals yield.

Xenotransplantation

This technology addresses a critical shortage of human organs for transplantation purposes. Altogether more than 62,000 patients are on waiting lists for lungs, hearts, or kidneys, and every day 11 of them die while waiting. The demand for transplants is growing, but the supply of human organs is not. The potential market is estimated at $10 billion per year.

Xenografts from pigs have several advantages:

- the supply is potentially unlimited (through cloning);

- pigs as sources of organs seem to be most nearly compatible to humans;
- the organs, tissues, and cells can, in principle, be engineered to overcome rejection; and
- it is possible to induce a recipient to tolerate a transplant by a variety of means.

The Big Bad Wolf and the Five Little Pigs

Echoing David Morgenthaler's observations, Dr. Ayares remarked that maintaining financial solvency can be difficult for a medium-sized biotechnology company, especially in today's volatile markets. From a financial perspective, most of the past decade has been hard on such companies. Some have gone out of business, and nearly all have been strapped for operating funds. To safeguard its future, PPL has built financial houses of straw, sticks, and brick for its xenograft program—just as the pigs in the old story did.

In this story the Big Bad Wolf represents these financial threats. There are five little pigs, not three, because that is the number of the first cloned litter of transgenic pigs.

PPL's xenograft program has the following specific areas of focus:

- hyperacute rejection (which we address by deleting the pig gene that produces a particular sugar molecule that evokes this violent and catastrophic rejection mechanism);
- delayed xenograft rejection;
- T cell-mediated rejection; and
- pig development.

To pursue these problems, the company has spent $8 million since 1996 on research in the United Kingdom and the United States.

"And He Huffed and He Puffed..."

PPL Therapeutics, the parent firm, raised $34 million near the fourth quarter of 1998. It was spending at the rate of about $20 million annually, with two products in clinical trials and no corporate partner for one of them. The company knew it would run out of money by the end of fiscal 2000. The board of directors was calling for the company to focus on its lead products (proteins in milk), and the xenograft program was given until September 1999 to find a partner or be forced to shut down.

To raise money, we aggressively pursued deals with several large pharmaceutical companies and with other xenograft companies. We wrote a business plan, which we showed to venture capitalists and private investors. We also pursued joint ventures. None of these efforts bore fruit. Risks and costs were too high, and payoffs too distant for potential investors.

Time was running out for us. But then we stumbled on the ATP. One of our senior scientists—Irina Polejaeva—met an ATP officer at an embryonic stem cell meeting in Madison, Wisconsin. After discussing the xenograft work, the officer suggested we should submit an ATP proposal.

Once we understood that the program was open to us, we submitted an ATP proposal, "Cloning Pigs: A Solution to Overcoming Rejection in Organs for Transplantation." Its goals were fourfold:

1. develop gene knockout technology in primary pig cells, using a knockout gene, the alpha 1,3-galactosl transferase gene;
2. develop pig cloning technology;
3. clone pigs using the genetically modified alpha-1.3-GT gene; and
4. use success in the preceding to develop strategic alliances for commercialization.

By the second quarter of 1999 we were still burning $18 to $20 million per year. We had lost our lead partner for AAT—our main product. The big pharmaceutical companies decided that investments in xenografts were too long-term and high-risk for comfort. Our business plan was still in the hands of venture capitalists, who had not offered funding.

PPL made the first cut of the ATP selection, and was invited to give an oral defense in June 1999. On October 6, we were awarded an ATP grant of $2 million over three years.

But our partners in AAT were still awaiting the results of phase II clinical trials. We were still spending $20 million a year, and the board decided that spending needed to be cut substantially to give the company time to achieve some product revenues from AAT. PPL cut its U.K. and U.S. staff by 30 percent. PPL, Inc.—the American company—lost 12 of its 34 employees. Research on rabbits (to produce calcitonin) and cows (for a variety of useful proteins in milk) was dropped.

Life Inside a Brick House

But as news of the ATP award spread, the phone began to ring. Big pharmaceutical companies who previously thought our research was too risky, wanted to talk. Venture capitalists were no longer hemming and hawing when we talked to them; they wanted to talk about structuring a spin-out company. Xenograft companies are trying to license the patents and otherwise cooperate. The stock price has doubled, giving a market value $80 million. And the board of directors is willing to support xenografts as long as it takes to find a partner, whether it is a major pharmaceutical company or a venture capital firm.

On March 5, 2000, the world's first cloned pigs were born. We have teams of world-class scientists working toward clinical trials, commercialization, and great medical and economic benefits. The future we envision is an infrastructure of high-technology pig farms and associated products and services that will make transplantation safer, more convenient, and easier to arrange. The backlogs will disappear. For thousands of people each year, life will be transformed from a steady decline to full health.

Without ATP there would be no cloned pigs. Success would have been delayed by years, and perhaps forever. The entire field of xenotransplantation would have withered or shrunk. The big bad wolf of inadequate financing would have won.

EXTENDING CASE STUDY METHODOLOGIES FOR TECHNOLOGY POLICY EVALUATION

Todd A. Watkins
Lehigh University

Inadequate Incentive for Innovation

The links between competitiveness and technology, and the questions those links raise for technology policy or, more broadly, industrial policy, have major implications for a nation's wealth, living standards, and national security. Policymakers and economists have long understood technological innovation as important for economic growth. It is also well understood that under some circumstances competitive markets will fail to generate adequate incentives to innovate.

Market Failure and Spillovers

The market failure justifications for government support of R&D are well rehearsed and widely discussed in the innovation economics and technology policy literature. Three main market failures are ubiquitous for R&D: increasing returns, from both externalities and indivisibilities (such as fixed R&D costs), and uncertainty. All are important for thinking about science and technology policies, but the increasing returns due to non-rival-good externalities are of most relevance for the ATP's focus on spillovers.

Empirical evidence from a wide variety of studies, industries, and methodologies supports the view that the social benefits of R&D are consistently high and, importantly for policymaking, higher than the private benefits, by factors typically ranging from 30 to 80 percent and sometimes as much as 300 percent. The persistence of high social rates of return to R&D is an indication that not enough is being invested in R&D from a social maximizing point of view. Otherwise returns to R&D would return to more normal rates.

Recognizing this chronic underinvestment, when the ATP was created by the Omnibus Trade and Competitiveness Act of 1988, its goals were "to assist U.S. business in creating and applying the generic technology and research results to

(1) commercialize significant new scientific discoveries and technologies rapidly and (2) refine manufacturing technologies" (P.L. 100-418). This has since been reformulated to emphasize that the ATP will foster economic growth and the competitiveness of U.S. firms by advancing technologies that have potentially large net social value for the nation but would not otherwise emerge in time to maximize their competitive value.

By subsidizing specific commercially-relevant high-risk R&D projects, the ATP aims, among other things, to accelerate the benefits from emerging technologies, to widen potential applications areas, and to increase the likelihood of technical success. In other words, the economic rationale for the ATP is, at its core, an R&D market failure argument. Hence, maximizing net economic spillovers is a central policy goal. By extension, a central issue for policy debate, program design, and program evaluation is whether the ATP succeeds at fostering spillovers and how it might increase them.

Research Support: ATP Awards Do Generate Technical Advance and Positive Spillovers

From the ATP Economic Assessment Office, there is a growing body of research evidence that ATP projects do indeed foster technical advances, increase the competitiveness of participating firms, and generate positive spillovers. However, as mentioned above, a wide variety of empirical studies of industrial R&D, including privately funded R&D indicate that R&D on average does all three as well, whether funded by the government or not. It is insufficient for ATP evaluations to find only increases along these three dimensions. To be shown effective, the ATP must succeed in sponsoring technologies with above average net return to the nation and that would not have emerged without the ATP.

Key Questions

Does the ATP deliver as advertised? Four questions are central to previous ATP evaluation research.

1. Is knowledge advanced? Have ATP projects advanced scientific and technological knowledge?
2. Is company performance improved? Have ATP projects increased the economic and competitive performance of U.S. companies?
3. Are there net spillover benefits? Have ATP projects generated additional net benefits that spillover to the broader economy of non-participants?
4. Does ATP pick the right projects? Does it succeed in identifying high-spillover projects relative to what would happen without it?

Questions 1 and 2 are the most straightforward to investigate and have been the principal focus of most existing ATP evaluations. They also have the clearest affirmative evidence already. Questions 3 and 4 remain significantly underexplored because the methodologies previously employed did not enable investigating them. For example, most existing ATP evaluation studies use only ATP participants in their research designs. So, even though questions 1 and 2 are the most straightforward questions, most of the studies acknowledge that they will miss advances in organizations that do not participate in ATP, such as competitors, suppliers, and those in largely unrelated markets.

Direct Evaluation and Counterfactuals

Existing evaluation methods begin by estimating the direct effects of ATP on its participants (gathering data through interviews, surveys, document review and/or expert forecasts) using metrics such as revenues, productivity gains, resource savings, decreased product maintenance costs, improved product quality, or reduced time required to launch new products. Evaluating the incremental effect of the ATP award then is a counterfactual (or countertemporal) exercise of comparing the current (or estimated future) state to what would have been (or was before) without ATP. However, by not including non-participants, the studies either ignore or have to estimate indirectly any effects (positive or negative) on the competitiveness of other players such as suppliers and competitors in the market.

Multi-Flavored Spillovers

Existing studies' focus on ATP participants is even more problematic when it comes to evaluating Questions 3 and 4 on spillovers. Part of the methodological problem is that spillovers come in two flavors:

- those to customers, competitors, and suppliers within the markets served by the innovators (so called market spillovers); and
- those to others not in the same markets, perhaps even completely unrelated to the innovator (otherwise known as knowledge spillovers).

In particular, it has limited ATP studies almost exclusively to market spillovers and, indeed more narrowly, almost exclusively to market spillovers to customers/users. Explicit evaluation of knowledge spillovers (value created for those other than players in the target market) is conspicuously absent. Nor can such participant-user isolated methodologies be of significant help in understanding spillover pathways or factors that facilitate or inhibit them.

Capturing the Social Value of Market and Knowledge Spillovers

So, how can case study methodologies be improved to more explicitly account for both market spillovers and knowledge spillovers? We extend the traditional case study methodology of Mansfield et al. in two significant ways that we believe are unique.[21] Implicitly, case study methods to date exclusively have focused on market spillovers. Knowledge spillovers have generally been the implicit focus of statistical studies using aggregate industry statistics, patent analysis or macroeconomic modeling. I am unaware of any study, either within or outside of ATP, of the returns to innovation that explicitly attempts to track both market and knowledge spillovers. It is clear that both are relevant to measuring the social value of innovative activity. It is unclear whether existing methodologies significantly misestimate spillovers by not explicitly accounting for both.

Snowballs: Mapping Technology Diffusion

To explicitly investigate both market spillovers and knowledge spillovers through case studies, the first methodological extension we developed was a combination of a snowball interviewing process—to identify and then include in our interviewing key customers, suppliers and competitors for market spillovers—coupled with patent and publication citation analysis to identify organizations outside the target markets for knowledge spillovers. We are thereby mapping the technology diffusion process at least one layer into the broader network by including in the case non-participating customers, competitors, suppliers, and other organizations.

Finally, the second methodological extension concerns the means of accounting for the economic value of technologies displaced from the market by innovations emerging from the projects. In theory, the incremental economic value attributable to an innovation (and, by extension, policies that support them) nets out the economic value of what would have been if the innovation had not occurred. This is either (or both) a forecasting or historical counterfactual exercise, subject to large uncertainties and subjectivity.

Dynamic Displacement

In empirical practice this fact has required subtracting for the forecast value of the displaced defender technologies already in the market. Note, however, that this counterfactual, "compared-to-what" valuation of a new technology takes a static view of the "old" market. It essentially ignores the potential value of parallel research projects elsewhere, the results of which were not yet in the market. However, parallel research projects among competitors are likely within markets characterized by dynamic strategic interaction among competitors in rapidly moving high technology. When a new innovation enters a market, it might not only

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[21] See E. Mansfield, "Social and private rates of return from industrial innovations," *Quarterly Journal of Economics*, 91(2):221-240, 1977. See also Z. Griliches, *The Search for R&D Spillovers,* Cambridge, MA: Harvard University Press, 1990.

displace the existing defender in the market but also preempt a second, or third or more almost-rans that would have otherwise emerged. We call this "dynamic displacement" and believe it is theoretically superior and in the context of counterfactual estimation no more subject to error empirically.

When both the R&D race winner and loser are U.S. firms, then using a static defender technology to evaluate the value of the winner's R&D will lead to overestimates of its net value to the nation. If government subsidies were responsible in part for the emergence of the first new technology, the appropriate subtraction for "compared to no government subsidy" would include the value of whatever second new technology (if any) would have eventually emerged instead. Subtraction only for the static old technology is appropriate only when no competitive parallel R&D project would have been eventually successful.

To take an extreme example to make the point, an evaluation of the economic value of government funding of CERN, the European particle physics research center, could add up to literally hundreds of billions, and perhaps trillions, of dollars, because CERN invented the World Wide Web (WWW). Clearly the WWW stimulated a very large share of the Internet economy. But we would only assign all those trillions as returns to government funding of CERN if we believe that no one else would have developed any alternative. Given how rapidly computer and semiconductor and software technologies have advanced, it is impossible to believe something else like it, would have escaped the world without CERN. CERN, though out front, was not alone in seeking relatively easier access to widely dispersed electronic information. In other words, organizations operating in similar technological areas tend to face similar innovations possibilities frontiers. Would we really all still only be using Veronica and Gopher through Unix instruction sets?

Static vs. Dynamic Models

The empirical attraction of the static defender is that it is known. Dynamic also-rans are counterfactual. Yet to assign value to a static defender in empirical practice, we also undertake counterfactual historical and forecasting analysis: what would the world have been like in 1990, 1995, and 2000 if it were still using only Veronica and Gopher? We see little reason to believe that estimates like this will on average be better than estimates to dynamic questions such as: who are the two organizations that you believe were closest to introducing similar technologies?; or how many more months or years longer might it have taken them to introduce it? In addition, by using a snowball interviewing process, such estimates can be verified or modified by then going to interview the two organizations thus identified.

So, where counterfactual estimation is necessary, we are investigating a dynamic interpretation of the defender technology for determining the counterfactual economic value displaced by innovations, comparing both a static and dynamic defender interpretation in order to evaluate the difference between the two approaches in terms of their estimates of net social value as well as their empirical feasibility.

ECONOMIC RETURNS TO NEW MEDICAL TECHNOLOGIES

Tayler H. Bingham
Research Triangle Institute

Mr. Bingham recalled prehistory, a time when the inventor and the person with the need for an invention were probably the same person. Surely a farmer invented the plow. The industrial revolution, however, was a period of the division and specialization of labor. Different people in different places, embedded in different organizations performed different activities. This trend has not abated. We are continuing to grow more specialized. Markets were traditionally viewed as effectively coordinating the various productive activities quite well, at least until the early part of the twentieth century. Prices sent approximately the right signals about the values and costs of products and services.

The modern view has become more sophisticated. We now discuss the possibility of so-called market failures. Some of the benefits of certain economic activities (such as research and development) are not always appropriable by those who undertake them. The implication is that the returns to the inventor and the returns to society differ. Where there are market failures, private markets do not provide the socially desirable type and number of goods such as R&D, and the government has a role.

He and his colleagues at the Research Triangle Institute (RTI) assessed the economic impacts of NIST support for new medical technologies for the ATP, under contract to NIST.[22] Dr. Sheila Martin (who has since left the Center to become policy advisor to the Governor of the State of Washington) directed the study.

They found that there are a number of reasons to believe that the difference between the benefits to society and those to inventors is large in the medical field. The ATP is one response to this gap between the public and private returns to R&D.

Seven Projects Assessed

The RTI team worked with NIST on seven multiple-application tissue-engineering projects, including projects addressing the diagnosis and treatment

[22] S. A. Martin, D. L., Winfield, A. E. Kenyon, J. R. Farris, M. V. Bala, and T. H. Bingham, *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies: Preliminary Applications to Tissue Engineering Projects Funded from 1990 to 1996,* prepared by the Research Triangle Institute for the Advanced Technology Program, NIST GCR 97-737, April 1998.

of diseases such as cancer and diabetes, the treatment of damaged ligaments and tendons, and procedures for the transplantation of xenogenic organs.

Methods Used: Life Without Railroads

To evaluate the potential contribution of ATP for the tissue engineering projects requires the need for a counterfactual—what would have happened without NIST support? To address that question, they borrowed a technique used by Robert W. Fogel in 1964.[23] Fogel wondered what the economy would have looked like in 1890 if railroads had never been developed—that is, if the defender technologies, such as rivers, canals, and roads, had prevailed as the nation's dominant transportation networks. In modeling this counterfactual world, he found that the railroad had contributed only 5 percent to economic welfare.

They posed a parallel question. They sought to compare the benefits and costs of the new health technology including the effects of the investments made by the ATP, with those of the defender technologies (the "non-ATP" case). They modeled the entire process, from R&D to health outcomes. RTI assumed that the innovators are rational: they are motivated not by curiosity, but by the chance to earn income from their technologies.

Shakespeare's Metric

How do you measure the health consequences of these technologies? Shakespeare, in *As You Like It*, identified seven ages of man, in which we start out in dependency and eventually end up in dependency again. A person's health stock does decline over time. But there are ways to improve our health, and the impacts of these techniques can be measured. They used a measure called the "quality-adjusted life-year" as a gauge of the health quality impacts of the technologies. Figure 3 illustrates the concept schematically.

Briefly, a person who is in perfect health is assigned a value of 1; a person who is dead is assigned a value of 0; and those at other states in between the two are assigned values in between. Estimates of where one is located along the spectrum, given an illness or disease, are based on interviews by health workers with people in various states of health.

The team estimated the statistical impacts of the technologies on the health of a cohort of patients and then calculated the probabilities of improvements in their health as a result of the impacts of NIST support of those technologies.

[23] Robert W. Fogel, *Which Road to the Past?: Two Views of History,* New Haven: Yale University Press, 1964.

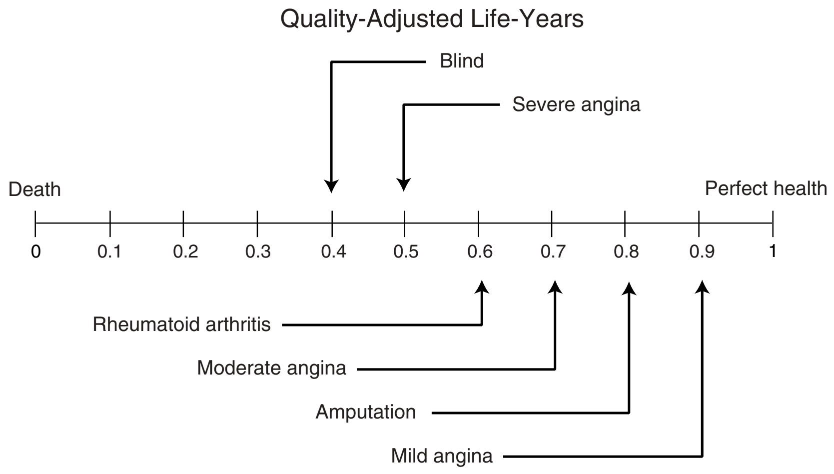

FIGURE 3 Schematic illustration of quality-adjusted life-year concept

The final question they addressed is "How much does society benefit from the contribution of NIST to these technologies?" The technologies are linked to the national economy by

- wage and salary incomes;
- owners' profits;
- tax payments;
- health expenditures; and
- health state, as represented by the value of a quality-adjusted life year.

The value of a life-year is traditionally estimated by economists according to people's willingness to pay to save or extend life. Statistically, this figure is about $7 million per life. The value of a life-year is valued something in the neighborhood of $0.25 million. Using this measurement, it is then possible to adjust for quality of life, in calculating society's benefit from medical technology.

Summary of Findings: Higher Social Returns

The study estimated the expected social return on the public (ATP) investment in these technologies at $34 billion, in net present value terms, or an IRR (internal rate of return) of 116 percent. The expected total social return on both public and private investments is estimated at $109 billion, net present value, or an IRR of 115 percent. The expected total private return on these investments is estimated at $1.6 billion ($914 million of it attributable to public funding), net present value, or an IRR of 12 percent.

These results illustrate two important points about ATP's role in funding these technologies:

- the ATP significantly impacts the expected social and private returns on these projects; and
- the social returns are far greater than the private returns. Private companies, therefore, tend to underinvest in these technologies from society's standpoint. For this reason public incentives to the private sector are important in pursuing these technologies.

Because the seven technologies studied have not yet been applied, the study is a prospective one, based on preliminary results and on the expectations of the innovators involved and other informed people. Whether these expectations will be met is uncertain. However, the methodology developed in this study will allow ATP to update the results of this study, as more data on actual applications become available.

DISCUSSANT

Henry Kelly
White House Office of Science and Technology Policy

High Public Returns on R&D

Henry Kelly of the Office of Science and Technology Policy in the White House, recalled Harry Truman's perhaps apocryphal dictum: "If you took all of the economists and laid them end to end, they'd point in all directions." With respect to the ATP, there is one place they all point in the same direction, that is, their agreement that the social rate of return to R&D investments is much higher than the private rate of return to R&D investments. It is beyond debate at this point.

In fact, we are probably underestimating the social rate of return, because there are so many intangible factors that are not measurable. The complexity of these spillovers for example—with knowledge spreading in a network of interactions among researchers in different fields and with different goals—is difficult to capture in an economic model. If one speeded up the development of one technology, how would that result propagate through the rest of the R&D system? Externalities that are not captured in conventional markets, such as the value of an additional year of life—or of a better, healthier life—are perhaps even more difficult to assess.

ATP: A Place to Welcome New Ideas

The Council of Economic Advisors[24] did a literature survey a few years ago showing that the average social rate of return to R&D is more than twice the private rate. The debate should not be whether there is an opportunity for public investment. The issue is whether we are doing it efficiently and well. We have a reasonably good track record in agencies with well-defined missions, such as the Departments of Energy and Transportation, and in areas where the government is the sole buyer, such as the Department of Defense and NASA. The exception is in the great collection of interesting and important crucial areas that do not fit in the missions of other agencies. The ATP has filled this important need. Uniquely in the federal government, it welcomes anyone with a great idea to apply for funding.

Close Scrutiny

The ATP is also unique in the extent to which it has been evaluated. The scrutiny applied to the ATP from outside has combined with its excellent evaluation staff to advance the science of economic evaluation.

"If We Didn't Have It, We'd Need to Invent It"

For all of these reasons, I believe, first, that there is no longer any debate as to the need for a program like the ATP. Second, after having responded and adapted to scrutiny over the past decade, the ATP is extremely well managed. The policy discussion at this point should be about how to carry it forward and continue improving it. If the ATP were not in place, addressing the problem of under-investment in R&D, we would need to invent something much like the ATP.

QUESTIONS FROM THE AUDIENCE

Social Return

Lewis Branscomb observed that private investments in R&D, like public investments, also produce excessive social returns. So what does the government do that is different? In other words, what market failures does the ATP address? The R&D "funding gap", or under-investment in R&D by the private sector, is the one most often mentioned. Yet there are others. The recent report *Managing*

[24] Council of Economic Advisers, *Supporting Research and Development to Promote Economic Growth*, Washington, D.C.: Executive Office of the President, 1995. See also National Research Council, *Conflict and Cooperation*, *op. cit*., pp. 33-35, Box A.

Technical Risk[25] identifies a list of institutional failures that may deter such investments even if they may be in the private interest of a firm. These institutional failures include difficulties in communicating between technical and financial people, lack of trust, and the risk-taking inhibitions of large firms. Together these failures provide even greater support for the need for public investments like those made by the ATP.

Funding Enabling Technologies

In response, Rosalie Ruegg explained that the ATP's purpose goes beyond merely compensating for the "funding gap." In focusing on "enabling technologies," ATP funds technologies that are expected to have broader than average spillovers. To document this point, she commended to the group several recent studies of the economic basis of the ATP.[26]

Proof of Concept

The ATP, said David Ayares of PPL Therapeutics, allowed his company to advance its xenograft technology to "proof of concept," at which point it was able to file for patents. Private investors regard a strong patent portfolio as important evidence of a small company's ability to go forward toward profitability. PPL has filed for two patents, and expects to file for one or two more. PPL has received no other public funding for this technology.

Todd Watkins picked up Rosalie Ruegg's point that the ATP seeks to fund "high-spillover" projects. The ATP should, he suggested, try to identify the factors that are related to high spillover. The ATP's Economic Assessment Office has commissioned a series of studies of sectors to identify such technologies.[27] He asked if spillovers are built into the selection process as explicitly as they should be.

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[25] Branscomb, Morse, and Roberts, *Managing Technical Risk, op. cit.*

[26] These included Austin and Macauley, *Estimating Future Consumer Benefits for ATP-Funded Innovation, op. cit.;* Branscomb, Morse, and Roberts, *Managing Technical Risk, op. cit.*; and Schachtel and Feldman, *Reinforcing Interactions Between the Advanced Technology Program and State Technology Programs, op. cit.*

[27] For example, Austin and Macauley, *Estimating Future Consumer Benefits for ATP-Funded Innovation, op. cit.*; and Martin et al., *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies, op. cit.*

Panel V: Assessing the ATP Assessment Program: Challenges and Policy Issues

INTRODUCTION

Charles Wessner
National Research Council

Charles Wessner opened the panel session by encouraging a free discussion of ways to improve the ATP assessment program, and, more broadly, ways to improve the program itself. These comments will be valuable to the NRC review of the ATP. To open the discussion, he asked John Yochelson, President of the Council on Competitiveness, to offer his views.

John Yochelson
Council on Competitiveness

Mr. Yochelson said that ATP must be improved steadily over time. Organizations either get better or they get worse. They do not stay the some. The program's mission—to funding the advance of enabling technologies that would otherwise not be funded—has not changed in the past decade. The environment in which it operates, however, has changed substantially in several ways.

A Change in Focus

First, the focus of concerns about competitiveness of the U.S. economy has shifted. Today the goal is to produce high-value or unique products and processes. When the ATP was founded, the problem was seen as an inability to produce competitive standard products and processes. The ATP responds to that change in the policy environment.

Globalization of Innovation

A second, related, trend is that the process of innovation is increasingly global, and its pace is accelerating. Companies turn knowledge into high-value products and processes at facilities throughout the world, sometimes on a twenty-four hour schedule. Furthermore, other countries are getting better at this kind of innovation. Again, this change plays to the ATP's strengths.

Changing Investment Patterns

Third, the private sector in the United States—especially in the past four or five years—has increased its focus on developing unique and high value products and services. This trend cuts the other way for the ATP, which is intended to compensate for companies' unwillingness to make such risky investments. As the federal share of R&D has declined, and private investment has moved into these areas. How can the ATP address that issue?

A Better U.S. Economy

Fourth, the U.S. economy is performing much better than it was in 1990. The sense of competitive urgency, on the parts of both industry and government, has improved. The federal budget is less constrained. These shifts would seem to favor continued support of the ATP.

Decentralizing Decisions

Finally, economic power has grown more decentralized. In the private sector, smaller, more agile, and more entrepreneurial firms have crowded out large firms as the engines of growth. In the public sector, much political power has flowed to states and localities. ATP must take advantage of this change.

Maryann Feldman
Johns Hopkins University

Adding Other Stakeholders

The day's program, Dr. Feldman said, was a heartening display of the rigor and seriousness with which ATP and its partners in industry have taken their responsibilities for the program. In particular, viewpoints of large and small companies had been well explored. She suggested that in future more university representatives be invited to participate. State and local governments also should be involved, since they are increasingly responsible for promoting technology development and innovation within their borders.

A New Program with a New Paradigm

ATP, she added, represents a paradigm shift in the economics of public R&D funding. Traditionally economists have looked at government programs as procurement-type programs, which could be analyzed in the aggregate terms of displacement effects and the like. But the ATP offers a new way of partnering and leveraging public and private resources. It is critical that economists who do assessments understand the implications of this change.

William Bonvillian
Office of Senator Joseph Lieberman

ATP vs. MEP

Mr. Bonvillian drew the group's attention to the divergent political paths taken by the ATP and MEP. Although founded at the same time, under the same legislation, MEP developed and spread nationwide quite smoothly, with little meaningful opposition. The ATP's course has been erratic, particularly in terms of its funding; today it is probably stable, but we should not be complacent about its future.

The Need for a Stable Political Model

If the ATP is truly a paradigm shift—if it is truly a way out of the Valley of Death in which America's small firms found themselves a few years ago—then we should seek a new and more stable political model for it. MEP is a program that was created for governors and states. It has a built-in support group in every statehouse and governor's mansion. Governors are proud of their MEP outreach programs. MEP is also popular with industry. As a result, it benefits from an ongoing lobbying network centered in the states and extending down to the grassroots of hundreds of thousands of small manufacturers.

Substantive Success and Political Instability

The ATP is a wonderful success in technical terms. But the designers of the program may not have created the right political model for it. The political model was based on substantive considerations. We wanted to discourage repetitive participation by companies, as in the SBIR. We wanted to focus on smaller and midsized firms. We have been successful in meeting most of these goals. But we missed the chance to create a strong political base.

Congress sometimes creates poor quality programs with strong political support. Can we create a high-quality program, like the ATP, with similarly strong support? The trick is to take a page from MEP's book and bring the governors and states into the picture.

Modern economic development policy, after all, stresses the development of regional clusters of industry. The ATP contributes to that strand of policy and should be given political support that corresponds to its substantive excellence.

David Goldston
Office of Congressman Sherwood Boehlert

The Need for a New Rationale

David Goldston agreed that the ATP seems to be stuck politically. In Congress the controversy over its funding has assumed the character of an annual ritual. One reason is that much of the program's original rationale—the specter of a hypercompetitive Japan, for example—is no longer taken seriously. The ATP today is, for many, a political symbol of an inappropriate role for government in helping industry. Accordingly, we need to develop a new rationale which better reflects the conditions of today. The ATP cannot survive, let alone grow, if it does not bring itself up to date in this important respect.

Economic vs. Technology Development

Bill Bonvillian's proposal for a nationwide network of political supporters at the grassroots would require a radical rethinking of the program. Congress traditionally has distinguished between economic development programs and science and technology programs. In the former (characterized by MEP) states are active, and political lobbying is expected. Science and technology programs (DARPA's, for example) are expected to be governed by impartial merit review and immune from political considerations. The most conspicuous programs that bridge these two models generally involve pork barrel spending for universities, supported by states. Usually these projects are widely deplored.

The ATP assessment process has had an important impact on the political environment, by making it hard to attack as simply poorly run. One no longer hears this argument much. But, as Irwin Feller pointed out this morning, these assessments must be viewed primarily as contributions to the way the program is run, and not as a panacea that will eliminate the political debate. That debate dates back 200 years, and one can always formulate legitimate questions that cannot be satisfactorily answered by the output of an economic model.

Economists, beyond their role as evaluators, need to learn how to help answer the vital questions about ATP. What are the real gaps and unseen failings in the current economy, and is the ATP designed to address them? We must be prepared to debate those questions? The existing dependable battle lines cannot be depended on for the friction that keeps the program going forever.

Todd A. Watkins
Lehigh University

From the Hill's perspective, Dr. Watkins said, the search for political traction for the program depends on the ability of the ATP to build relationships. As Kathleen Kingscott told us this morning, even a company as big and global as IBM finds the ATP valuable as a source of new relationships with R&D partners and suppliers. Elizabeth Downing, CEO of a tiny new company, finds the ATP useful as a kind of marriage broker—a source of new contacts.

Building "Social Capital"

In this role, the ATP reduces what economists call the transaction costs of building partnerships or social networks. These social networks are the basis of what many scholars today call "social capital," which is thought to promote a strong and flexible social order but is not provided by markets. This social capital—expressed through collaborative relationships—may offer political advantages to the ATP's supporters. The program might stress this aspect of its mission more publicly, for example, through a variety of means, such as workshops and publications.

This lesson is one that can be drawn from the European equivalent of the ATP, the Framework technology program (originally called *Esprit*). This program predates the ATP by several years.[28] It was based on a similar market-failure argument. As the Europeans gained experience with the program, it began to stress the social capital contributions of the program, which in Europe has great political salience.

One should be skeptical about applying macroeconomic analysis to the ATP. Plugging microeconomic data, such as dollar cost savings of individual compa-

[28] For a description of the Fifth Framework Programme (1998) see Jorma Routti and William Cannell, "European Union Research Programs," in National Research Council, *New Vistas in Transatlantic Science and Technology Cooperation*, Charles W. Wessner, editor, Washington, D.C.: National Academy Press, 1999, p. 103. This program favors "partnerships and networks of research actors, public and private, which are more strongly oriented towards utilization and uptake of results" (p. 103). "The majority of the funding to date has been allocated to five broad themes: energy, life sciences, environment, industrial and materials technologies, and information and communications technologies" (p. 105). Funding for the Fifth Framework is 14.96 billion Euros over five years. http://europa.eu.int/comm/research/growth/leaflets/en/whatisthe5th.html.

nies, into macroeconomic models of the economy is a meaningless exercise. The ATP's budget of a few hundred million is "in the noise" so far as the national economy goes. Even in the case of defense—where much effort is spent trying to identify positive spillovers into the economy—it is hard to make such a case. The ATP should spend its money on the microeconomic studies.

QUESTIONS FROM THE AUDIENCE

Larry Rhoades said that he found attempts to compare MEP and the ATP troubling. The two programs have vastly different focuses. MEP (on whose National Advisory Board he sits) is devoted to keeping small manufacturers relatively up to date by addressing their rather well-defined and common problems; it therefore is appropriately handled regionally. The ATP, on the other hand, seeks original solutions to unique problems, which cannot be constrained by state borders. The ATP could do two things to improve itself:

- spend even more effort on evaluating the program and tightening its management, to build support for the idea that the program is a revenue enhancer, and not an expenditure program; and
- build relationships between product and process developers.

Charles Wessner asked the group to comment on the extent to which evidence of positive spillover to the economy would be politically persuasive to policy makers.

Creation Myths

Only to a limited extent, said Mr. Goldston. Many science and technology programs have "creation myths" that give them the aura of solid and sustained national contributions, whether earned or not. DARPA and NSF, for example, are credited with the creation of the Internet, and are supported for that reason. NIH, similarly, is given credit for all health advances. The ATP does not yet have such a reputation for national achievement.

Reviewing the extent of local and sectoral support for the ATP, it was observed that the ATP at one point had "focused" competitions in particular sectors. Additionally, ATP partnerships often spread quickly beyond the locality of the original grant performance.

Mr. Bonvillian emphasized that the ATP and MEP are very different programs serving different constituencies. The ATP must retain its focus on high-risk technology. But the intense and broad political support for MEP is an important feature of that program. The ATP has no structure for involving business, universities, and local and state officials. Every governor has a sense that new technology is an important driver of growth, but ironically there is no grassroots support in the states. He added that this may also be an issue of program scale. The ATP may lack the critical mass to develop widespread support.

An Illegitimate Role?

David Goldston responded that MEP has never had organized and committed political opposition. Its activities—economic development through industrial extension—are nearly universally accepted as a government mission. The ATP, on the other hand, has always attracted the attention of some in Congress and elsewhere who regard commercial technology development as a fundamentally illegitimate role for the federal government. The ATP might find wider support if it offered, separately from the grant-making apparatus, regional services such as clearinghouses for technical information, on the model of MEP.

A Regional Approach

John Yochelson asked whether a regional approach might mitigate some of the disadvantages of the state-based approach. Regional associations of states are quite common for dealing with problems that extend beyond state borders. If such an organization crossed party lines and offered a way for states to cooperate, it might prove popular with governors and state business associations, whose support for the ATP is now lukewarm.

David Goldston pointed out that such an approach would solve some problems, but produce others. There would be great pressure to spread resources evenly around the country, with one such center in every region, without regard for technical excellence. Such rhetorical strategies may be useful in the short term. For example, the university pork barrel movement began with the public recognition of universities as engines of economic growth, and quickly took on a life of its own, creating pressure to distribute funds and programs nationwide.

William Bonvillian said he doubted that a regional organization would promote enough political horsepower to build stable support. He would oppose efforts to reduce the merit basis of ATP grants. Still, a program structure that allowed more governors to take credit for successes would clearly bring advantages.

Globalization?

Referring back to comments on the globalization of R&D, Charles Wessner observed that the term "globalization" is often used loosely. In fact, products are assembled and marketed globally, but technology tends to be developed in local concentrations. The American economy's ability to spring back from competitive challenges may be due in part to this local concentration of specialized skills, the deep U.S. capital markets, and the relatively lower penalties for failure among U.S. entrepreneurs. When special effort is required, public alarms are raised over specific competitive challenges. In contrast to that of most industrial nations, U.S. policy rarely gives the same level of sustained attention to the nation's technology and manufacturing base.[29]

A Need for Structured Programs

Lewis Branscomb regretted the loss of the ATP focused programs. NSF's multibillion-dollar initiative in K–12 education—not traditionally a federal concern—achieved support, he pointed out, because it addressed an undisputed problem by applying the best available expertise. Similarly, he suggested, the ATP could assemble a series of sectoral programs to identify competitive problems with technological implications. These programs could build support through partnerships of industry, labor, universities, and state and local government, committing them to act on business problems, with the federal government offering an injection of technological expertise. Such a program would have the advantage of being big enough to be visible on a national scale and focused enough on local problems to generate committed and bipartisan support.

Jean Powell of the ATP assessment staff responded to Todd Watkins's suggestion that macroeconomic impact studies be de-emphasized by ATP in favor of microeconomic studies. In general, she said the ATP management agrees and does not do much macroeconomic study of its spillovers. The main exception, in fact, is the automotive project reported on earlier by Mark Ehlen and Larry Rhoades.

An Experiment in Selection

Elizabeth Downing said that the forces arrayed against the ATP have argued that the private sector would step in, absent the ATP, to fund these long-term investments in enabling technologies at these early stages. As a scientist, she proposed an experiment, in which the selection process would be changed to include representatives of the financial community. A panel of venture capitalists could be allowed to review applications, and given access to any of the technologies they found promising. That would settle the question of whether the private sector can serve this function.

John Yochelson asked whether a representative group of venture capitalists might be willing to testify publicly or privately to Congress that ATP does contribute to meeting the "funding gap."

[29] There are U.S. programs focused on general improvements in manufacturing, such as the Manufacturing Extension Partnership Program, and programs in the National Science Foundation Engineering Research Centers. There are also major programs focused on specific sectors such as the Partnership for the Next Generation Vehicle or the Advanced Battery Consortium.

Does ATP Generate Jobs on a Regional Basis?

Joel Yudken, AFL-CIO, warned that the group may be missing the political forest for the trees. The comparison with MEP may be misleading, since it has a very different mission. The ATP clearly addresses a market failure. Labor, for its part, will not lobby for the ATP unless there is a clear understanding of how it creates jobs and how it affects workers. Organized labor understands that new technology improves productivity and leads to growing incomes for workers. But it will need some clear evidence that ATP projects will pay off in these ways in the industrial sectors where unions are strong. Mark Ehlen's study is very persuasive in that respect and more use should be made of it in making this point. The likely regional distributions of new jobs is of particular interest. If the ATP is to prosper, it must show that it has a real payoff for real people, not just venture capitalists.

About 60 percent of ATP applicants, according to Maryann Feldman's study, are concentrated in four states, said Bill Jones. That result—which reflects the concentration of high-technology industry—is at the root of the narrow political support for the ATP. But perhaps a broader base can be built on the beneficiaries of these technologies, from organ transplant recipients to the drivers of automobiles.

THE ATP DIRECTOR'S THANKS

Alan Balutis, the new Director of the ATP, expressed appreciation of the impartial and penetrating analysis to be expected from the STEP Board's study. Rosalie Ruegg, he added, has built the ATP's assessment program into one that is unique in government. Her upcoming retirement is one of the few bleak spots in his outlook as the program's new director.

Concluding Remarks

Charles Wessner
National Research Council

After thanking the participants, Dr. Wessner concluded the proceedings with a few observations on the program and its goals. The first is that this meeting had again emphasized the quality and diversity of the ATP assessment effort. Based on several years of reviewing federal partnerships, the ATP assessment program clearly surpasses other U.S. partnership programs with its rigor, scope, and independence.[30]

Second, perhaps because of its generic nature, the program seems to have been required to meet a higher standard of evaluation than many mission-oriented programs, which have relied on cooperative research agreements (CRADAs), or significantly larger generic programs such as the $1.2 billion SBIR program. The fact is that the ATP assessment, largely conducted by independent economists, many under contract with the National Bureau of Economic Research, strongly suggests the program is meeting its goals. Few other federal programs have embraced this level and intensity of assessment and sought to apply its results as diligently as the ATP.

These observations are not meant to suggest that the program cannot be improved. Of course it can be, and the NRC report will no doubt make suggestions in that regard. Yet the ongoing evaluation of the program and its political difficul-

[30] D. Mowery emphasizes this point in “Using Cooperative Research and Development Agreements as S&T Indicators: What do We Have and What Would We Like?” presentation before the National Science Foundation conference, *Workshop on Strategic Research Partnerships*, 13 October 2000, publication of Proceedings pending. See also National Research Council, *The Small Business Innovation Research Program: Challenges and Opportunities*, Charles W. Wessner, editor, Washington, D.C.: National Academy Press, 1999.

ties should not be allowed to obscure what we have learned. There is a growing and increasingly weighty body of evidence indicating that:

1. The program is achieving its technology development goals in fields such as information technology and biotechnology. For example, the assessment program has recorded genuine advances in new processes and procedures for printed wiring boards, in the use of gallium arsenide to achieve improvements in integrated circuits, in testing and aligning extremely precise coated mirrors, and for enhancing data storage capabilities. In the field of biotechnology, it has supported advances in rebuilding lost or damaged human tissues, extracting more information from genetic sequencing of DNA, and in the development of bio-absorbable polymers for repairing bone fractures.[31]
2. Through its assessment program, close management oversight, and industry cost-sharing, it has developed an effective self-correction mechanism. Such mechanisms, and the flexibility they engender, are an essential feature of a modern technology development program.[32]
3. The technologies the ATP supports are meeting the program goals of

   - improved efficiency and competitiveness (e.g., Extrude Hone's contribution to manufacturing efficiency and the environment);
   - more rapid commercialization of new welfare-enhancing technologies with positive spillovers (e.g., the GE mammography diagnostic instrument);[33] and
   - development of significant new scientific discoveries, such as the PPL Therapeutics organ cloning.

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[31] For the description of these projects see Rosalie Ruegg, "Taking a Step Back: An Early Results Overview of Fifty ATP Awards," in this volume.

[32] See P. Grindley, D. Mowery, and B. Silverman, "SEMATECH and Collaborative Research: Lessons in the Design of High-Technology Consortia," *Journal of Policy Analysis and Management*, 13(4):736, 1996. The consortium's goals changed over time, reflecting the changing perceptions of its members' needs. The authors note that this operational flexibility is a strength and probably essential in an industry evolving as rapidly as the semiconductor industry. See also R. R. Nelson, *Government and Technological Progress*, New York: Pergamon, pp. 454-455, 1982.

[33] Recently approved for clinical use by the Food and Drug Administration, the new system represents a significant technological advance in breast cancer detection. It uses a unique amorphous silicon detector that provides high-quality imaging which can be digitally enhanced and rapidly verified. A 1995 ATP project awarded to General Electric and EG&G Reticon developed a new manufacturing process that significantly reduced the manufacturing cost of the amorphous-silicon panels used in the new detection system, making this superior detection system more affordable and available to a greater number of women. See http://www.nist.gov/public_affairs/update/upd000410.htm#Health

Common Questions

Today's discussion was particularly useful in that it clarified some common questions or misunderstandings about the ATP. For example, questions are often asked about the need the ATP fills for a small company, why a large company would or should participate in a government-supported program, and what need is met by the ATP that is not already met by the well-developed venture capital industry in the United States.

To take each question in turn, Elizabeth Downing provided insights concerning the challenges faced by a new start-up with a promising but technically challenging technology. Her views on the advantages of an ATP award are particularly valuable, perhaps unique, insofar as she has had direct experience with a variety of federal programs. The representative from IBM, Kathleen Kingscott, provided an equally valuable presentation explaining why even a major company with a large and successful internal R&D program finds it necessary to partner and finds the ATP an effective vehicle to collaborate on the development of enabling technologies. Perhaps most constructive was the presentation by David Morgenthaler, who not only outlined why venture capital and the ATP have inherently different objectives and functions, but also affirmed the need for more government investments of the type undertaken by this program.

Although several speakers suggested the scale of the program should be increased, the program's level of activity is significant. Over the last ten years, it has funded over 460 projects involving over a thousand participants in 157 joint ventures. These awards have accounted for $3 billion in funding for new technologies, with about half of the funds from industry, the other half from the ATP. Interestingly, small businesses play a dominant role in the program. The majority of the ATP awards, currently 66 percent, are made to small businesses, with about 25 percent going to small start-ups. The program has also involved a large number of universities and national laboratories.[34]

There was also much discussion of the extensive ATP assessment program. Importantly, these outside assessments, complemented by in-house evaluations, demonstrate that the program is achieving its goals in many cases—though not all—and terminating projects that are not achieving their goals. As noted, this ability to self-correct in a timely manner is an important feature of the ATP. The willingness to accept the inevitable failures and cancel funding is in itself a valuable aspect of the program and one which is unfortunately only too rare.

Government programs that can demonstrate an ability to meet their goals, particularly inherently uncertain R&D goals, represent policy success with potentially large benefits to national welfare, the accomplishment of government

[34] As noted above, through the end of 2000, the ATP funded 522 projects with 1,162 participants and an approximately equal number of subcontractors. Through that time, 176 universities had participated as well as more than 20 national laboratories.

missions, and the competitiveness of U.S. industry. Programs that can positively contribute to these goals can make important contributions to economic growth, national competitiveness, and human welfare. Indeed, as Professor Feller notes, the extensive ATP assessment program has led to significant progress in understanding important aspects of the U.S. innovation system and has supported the development of cutting edge methodologies for its analysis.

Changes Needed

As mentioned, there are clearly issues for the NRC assessment to address. For example, we should probably consider issues such as the timing and speed of the award process, the possibility of concentrating resources in thematic areas, better integration of assessment results in the decision process, and the need to ensure sufficient program scale for maximum impact. There is the related possibility of the program undertaking more "work for others" as do a number of the DoE laboratories, particularly with regard to tools and medical equipment. This was in fact suggested by Francis Collins of the National Human Genome Research Institute at the initial NRC meeting to review the ATP. Yet as the NRC study goes forward, it is important we note and record what the researchers and program participants—winners and losers alike—are saying. What they seem to be saying, and what the outside research shows, is that this is a federal program meeting its challenging goals.

V

RESEARCH PAPERS

The ATP Competition Structure

Alan P. Balutis and Barbara Lambis[1]
National Institute of Standards and Technology

INTRODUCTION: THE ADVANCED TECHNOLOGY PROGRAM

The Advanced Technology Program (ATP) of the Department of Commerce's National Institute of Standards and Technology (NIST) provides cost shared funding to industry to accelerate the development and broad dissemination of challenging, high-risk technologies that promise broad-based economic benefits for the nation.[2]

The ATP allows industry to extend its technological reach by funding:

- Emerging and enabling technologies that make possible the development of future new and substantially improved products, industrial processes, and services in diverse areas of application;
- Technologies for which challenging technical issues stand in the way of success;
- Technologies whose development often involves complex "systems" problems requiring a collaborative effort by multiple organizations;

[1] Alan P. Balutis is Director of the Advanced Technology Program. Barbara Lambis is the Senior Policy and Operations Advisor to the Director of ATP. This article was based on a draft prepared by Barbara Newland, who served as the ATP Competitions Manager until leaving government service on 11 November 2000.

[2] The ATP was established in 1990 under the Omnibus Trade and Competitiveness Act of 1988 (Pub. L. 100-418), as amended by the American Technology Preeminence Act of 1991 (Pub. L. 102-245).

- Technologies that, because they are risky, are unlikely to be developed or proceed too slowly to compete in rapidly changing world markets without the ATP.

The ATP funds technical research, but not product development (which is the responsibility of the private sector). The ATP is designed to be driven by industry: for-profit companies conceive, propose, co-fund, and execute all of the projects of which the ATP shares the cost.

For-profit U.S. companies may apply to the ATP either as single companies or as joint ventures. Single company projects, though proposed by a single company, usually involve other companies, universities, or other organizations as subcontractors or informal collaborators. Joint-venture projects must have at least two for-profit company participants. Joint ventures may include other members, including other companies of any size, governmental laboratories, universities, and other nonprofit organizations. Joint-venture members may also have subcontractor and informal relationships with others.

Sharing of costs is the essence of the program, and the cost-sharing requirements differ depending on how a project is structured. Single company recipients can receive up to $2 million for R&D activities for up to 3 years. ATP funds may only be used to pay for direct costs for single company recipients. Single companies are responsible for funding all of their overhead/indirect costs. Large, "Fortune 500" companies participating as single company recipients must cost share at least 60 percent of the total project costs. Joint ventures can receive funds for R&D activities for up to 5 years with no funding limitation other than the announced availability of funds. Joint ventures must cost share more than 50 percent of the total project costs. More than half of ATP awards have gone to single small company recipients or joint ventures led by small companies. On the average, ATP projects last a little more than three years. Figure 1 illustrates the two ways companies may apply.

A U.S.-incorporated company (subsidiary) of a foreign-owned parent company which is incorporated in another country may apply if the company meets the conditions in the ATP legislation.[3] Prior to a final award, a foreign eligibility finding is made by NIST which involves the collection of evidence that:

(1) the company's participation in the ATP is in the economic interest of the United States;
(2) the country of incorporation of the participant's parent company affords U.S.-owned companies opportunities comparable to those afforded to any other company to participate in government-funded programs similar to ATP;

[3] See 15 U.S.C. Sec. 278n. (d)(9) and regulations (15 CFR 295.3).

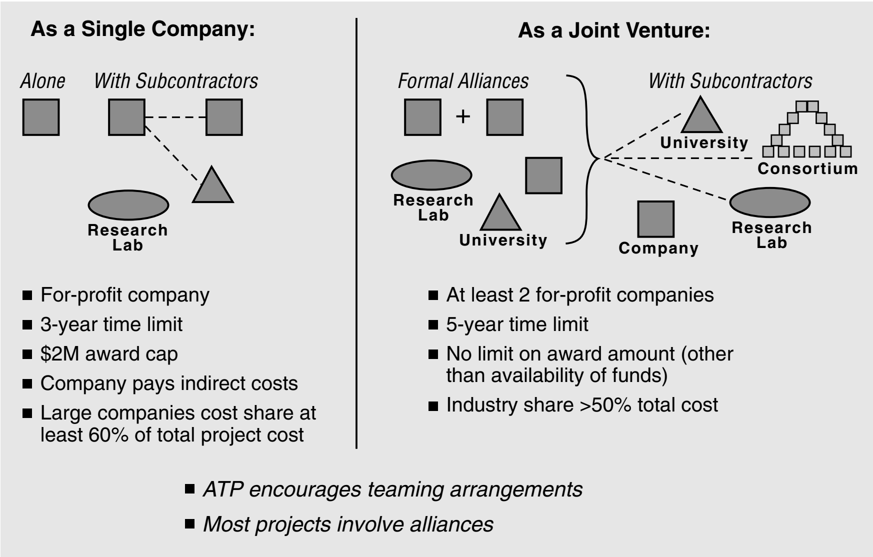

FIGURE 1 The ATP application process

(3) the country of incorporation of the participant's parent country affords U.S.-owned companies local investment opportunities comparable to those afforded to any other company; and

(4) the country of incorporation of the participant's parent country affords adequate and effective protection for the intellectual property rights of U.S.-owned companies.

ATP projects are selected through a highly competitive process. All proposals are selected based on a peer-review process using the established, transparent selection criteria. Only those proposals that are found to have both high technical and economic merit are selected for funding.[4]

The quality of the selection process is critical to the program's success in several ways. A sense of fairness and rationality in the selection process is important to the willingness of proposers to participate. The ability to select well and with efficiency is critical to the program's performance and its ability to achieve its goal of substantial net benefits to taxpayers.

This paper reviews the competitive structure of ATP's project selection process. It describes the basic principles that determine how the selection process is structured, and identifies the core components of all of the program's competi-

[4] For more information about ATP, its selection process, and selection criteria, see the NIST ATP web site: http://www.atp.nist.gov.

tions to date. It also reviews the evolution of ATP's competitive structure since the first competition in 1990.

KEY PRINCIPLES AND COMPONENTS IN PROJECT SELECTION

Key Principles

In establishing the process of project selection, ATP is guided by several underlying principles:

- **Responsiveness.** The competition structure must be responsive to industry, since U.S. businesses are the agents through which ATP achieves its mission.
- **Integrity.** The process must have integrity such that all proposals get a fair and consistent peer-review and are judged solely on how their proposal meets the published selection criteria.
- **Scalable.** The process must be scalable to allow for changes in the volume of proposals received, and revised in a timely manner to support growth.
- **Evaluation.** The process must produce the desired outcome; that is, a portfolio of projects that support the program's goals.

Key Components

In carrying out the project-selection process, the ATP uses several operational components:

- **Announcements of ATP competitions and selection criteria** alert industry of the opportunity and the challenge. Proposers' Conferences provide tutorials on the selection criteria and process.
- A **Source Evaluation Board (SEB),** a board made up of Federal employees, is convened to evaluate proposals against the selection criteria.
- **Expert technical and business reviewers outside the SEB** conduct independent peer reviews of proposals, which are provided to the SEB as advice in project-selection deliberations. All reviewers must be free from conflict of interest and must sign nondisclosure agreements. Outside technical reviewers are drawn from federal laboratories, and outside business/economics reviewers are hired consultants, with suitably diverse expertise in business operations, venture capital, economics, and business development.
- **Technology classification codes** are used to identify the principal area of technology. This information is used along with non-proprietary abstracts of the proposal in finding suitable reviewers and may be used to form

technical panels of SEBs. It is also used to track historical funding in various technology areas.

- **Preliminary screening** of all proposals identifies those with serious deficiencies, and these are eliminated from the competition.
- **SEB deliberations**, including evaluating proposals, as well as technical and business review; selection of semi-finalists, conducting face-to-face oral reviews with proposers, and ranking of proposals.
- **Selecting Official** makes final award selections.
- **Debriefings** provide feedback to unsuccessful proposers from SEB representatives on proposal strengths and weaknesses.

THE PROJECT SELECTION PROCESS

In brief, the process used over the past decade starts with ATP announcing a competition. One or more Source Evaluation Boards (SEB) are established to determine how proposals score against established selection criteria. A preliminary screening is performed for all proposals to identify those that have serious deficiencies and those that warrant further consideration. Independent reviews provided by outside technical and business experts are taken into account by the SEB in its consideration of each proposal. The SEB members discuss each proposal with reference to the selection criteria. If the Board members agree that a proposal is sufficiently strong in technical and business/economic merit, it is chosen to progress to the semi-finalist stage.

Proposers selected as semi-finalist proposals may be invited to NIST for an oral review (a face-to-face discussion with the SEB). At this meeting, which typically lasts about two hours, the Board members question the proposers about the proposal. Questions involving technical, economic/business and budgetary aspects of the proposal, and, where applicable, questions about human and animal subjects in research are raised. There may be questions that have been raised by various reviewers at any stage of the proposal review process as well as questions that arise during the oral review. From this process of review of both written and orally presented information about proposed projects, semi-finalist proposals are ranked and the Selecting Official chooses funding recipients based upon the ranking, the availability of funds, adherence to the ATP selection criteria, and an appropriate distribution of funds among technologies and their applications. Award recipients are announced and awards are made in the form of cooperative agreements between the award recipients and NIST.

Unsuccessful proposers are given the opportunity of telephone debriefings conducted with SEB members. The debriefing lets the proposers discuss their proposal's stronger and weaker points with those particularly knowledgeable, though the views represented reflect those of the entire Source Evaluation Board and provide insight into its deliberations. This information can be helpful if the company decides to revise and resubmit the proposal, submit another proposal to the ATP, or pursue the proposed research in some other way.

The debriefing feature of the ATP is popular. A recent survey of 1998 proposers showed that 63 percent indicated that they had participated in a debriefing, and 69 percent of non-recipients said they found the debriefings to be "very helpful" or "reasonably helpful."[5]

EVOLUTION OF THE COMPETITIVE STRUCTURE

The evolution of the competitive structure over the past decade is best understood when viewed against a backdrop of ATP's budgets, proposals received, and awards made, as illustrated in Figures 2, 3, and 4, respectively. The changing budgetary environment for the program has had a major impact. As Figure 2 indicates, through the initial years of the Bush administration, the program increased steadily, with substantial bipartisan support. In FY94-95, the program received substantial increases in funding. These were followed by a sharp decrease in FY96 from $340 million (after a recission) to $221 million. The program stayed in the $200 million range until FY2000, although the relative stability of this funding understates the political uncertainty associated with the program.

These changes in budgetary levels have substantial influence on both the number of proposals submitted to the ATP and how the ATP organizes its com-

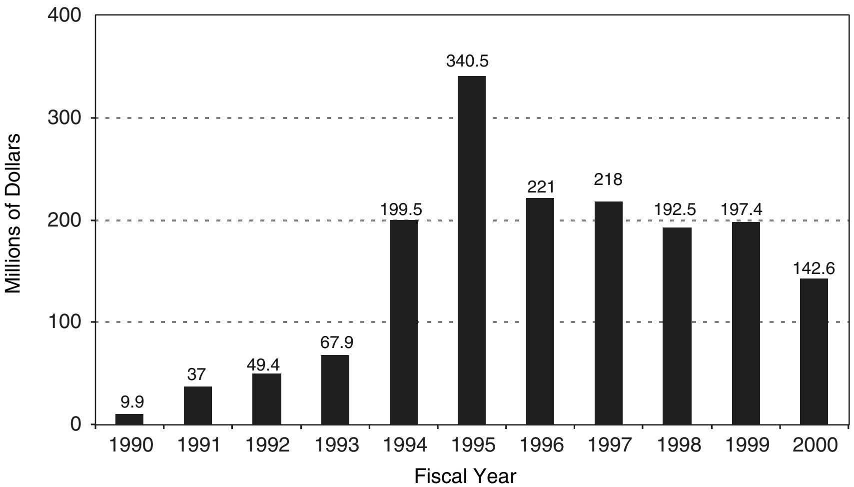

FIGURE 2 ATP appropriations, 1990-2000[6]

[5] The results of the survey are reported by M. P. Feldman and M. R. Kelley, "Leveraging Research and Development: The Impact of the Advanced Technology Program," in this volume.

[6] The initial appropriation for 1995 was over $430 million which, after a recission by the new Congress, was reduced to $340.5 million in April 1995.

petitive structure and operational processes. The evolution of the competition structure is described below. Four distinct periods are addressed: 1990-93, 1994-98, 1999-2000, and 2001.

General Competitions Only—1990-1993

From 1990 through 1993, the ATP was in its formative stage, with small but steadily rising budgets. Authorized for funding in 1988 during the Reagan Administration, the ATP received its first funding of just over $10 million in 1990 during the Bush Administration, and by 1993 its budget was more than $60 million. During these first four years, companies submitted in the range of 150-300 proposals per year, and the ATP made awards in the range of 10-30 per year.

In each of these years, the ATP announced a single "General Competition" and convened an SEB composed of about a dozen members, some with technical backgrounds and some with business backgrounds. Given the size of the competition, a single SEB of this size was able to process all of the proposals.

To provide advice to the SEB, the ATP obtained independent reviews from outside technical and business/economic expert reviewers. During these early years, the independent technical and business/economic reviews were conducted sequentially, with all of the proposals receiving technical reviews and only the semi-finalists receiving business/economic reviews. The independent technical reviewers were scientists and engineers drawn from government research laboratories, such as the National Institute of Standards and Technology, National Institutes of Health, National Science Foundation, Department of Energy Laboratories, and Department of Defense Laboratories. The first business/economic reviewers were primarily retired business executives.

General and Focused Competitions—1994-1998

The Clinton Administration designated the ATP as an important element in its economic plan, and slated it for rapid growth. Dr. Arati Prabhakar, appointed Director of NIST, added Focused Program Competitions to the General Competition that the ATP had used previously. The idea was to add depth in selected technology areas, while maintaining the open door to great ideas from all areas of technology. Focusing in selected technology areas would allow greater advanced planning and a coordinated approach by industry and government. This approach was expected to assist the scale-up of the program and increase impact by accelerating the development of the selected technology areas overall.

Opportunities Identified by Industry

The ATP procedures presume that industry is closest to the market and to the potential of a technology. To draw on this expertise, the specific technology areas for the focused competitions were chosen in a process that began with white papers submitted by industry. ATP staff then conducted public workshops to debate the suggestions and work with industry to refine the proposed technical scope. The merits of proposed focused competitions were judged on the following elements:

- Technical goals and program scope;
- Economic goals and scope of proposed work;
- Potential for broad-based economic benefits to the United States;
- Level of industry commitment and clear need for ATP support.

Focused programs were selected that best met the ATP criteria and could be launched with the available funds. During the period 1994-98, it ran focused program competitions in the following areas:

- Adaptive Learning Systems;
- Advanced Vapor Compression Refrigeration Systems;
- Catalysis and Biocatalysis Technologies;
- Component-Based Software;
- Digital Data Storage;
- Digital Video in Information Networks;
- Information Infrastructure for Health Care;
- Manufacturing Composite Structures;
- Materials Processing for Heavy Manufacturing;
- Microelectronics Manufacturing Infrastructure;
- Motor Vehicle Manufacturing Technology;
- Photonics Manufacturing;
- Premium Power;
- Selective Membrane Platforms;
- Technologies for the Integration of Manufacturing Applications;
- Tissue Engineering;
- Tools for DNA Diagnostics.

Several competitions were run for most of the focused-program areas, depending on industry interest, availability of funds, and continued robustness of the original goals. In 1994 there were six competitions (one general and five focused), in 1995 twelve competitions (one general and eleven focused), in 1996 one competition (one general), in 1997 seven competitions (one general and six focused), and in 1998 nine competitions (one general and eight focused). In 1994 and 1995 specific dollar amounts were allocated to each of the focused programs. (For example, in 1994 the Information Infrastructure for Health Care Focused Program was announced, with $185 million estimated as the cost over the several-year life of the program.) In total, the ATP awarded more than 150 cooperative agreements in focused program competitions.

During this same period, the ATP also held a General Competition each year to ensure that great ideas from technology areas not addressed by the focused areas had an opportunity to be funded by the ATP. While it awarded the bulk of its funding through the Focused Competitions, it also had robust General Competitions each year on the order of those held when the program was smaller.

The selection process for the General and Focused Competitions followed the same basic format as discussed above. Each competition was processed by its individual SEB, and there were as many SEBs as there were competitions.

Open Competitions—1999-2000

In fiscal years 1999 and 2000, the ATP suspended its Focused Competitions and developed a hybrid model. This model combined the strengths of the focused program competitions, which industry preferred, with the General Competition. The resulting competition structure was dubbed "Open Competition" to highlight its difference from the tradition General Competition. A single SEB was used for the selection process; however, the SEB was divided into multiple technology boards, such that proposals in each technology area were batched and reviewed by a board focusing only on that technology area. The 1999 Open Competition, for example, used five technology boards (biotechnology, chemistry and materials, electronics and photonics, information technology, and manufacturing). Because most manufacturing technologies were found to cut across other technologies, the 2000 Open Competition merged the manufacturing proposals into the boards with the appropriate application area.

The 1999-2000 change reflected several developments. The originally expected increase in the program funding to approximately the $1 billion level had failed to materialize. Consequently, there was insufficient funding to support industry's demands for multiple focused program topics. By this time there were more quality focused program recommendations than ATP could support. At the same time, some members of Congress were voicing stringent objections to the focused program mode of competitions, and annual uncertainties about funding levels continued.

Competition-Dependent Variations in the Selection Process

Although the basic selection process has remained relatively constant over the last decade, the type of competition has caused some variation in certain steps of the process. Examples follow:

Preliminary Screening

In Focused-Program competitions, each proposal was initially screened by the SEB to determine whether its technical scope was consistent with the appro-

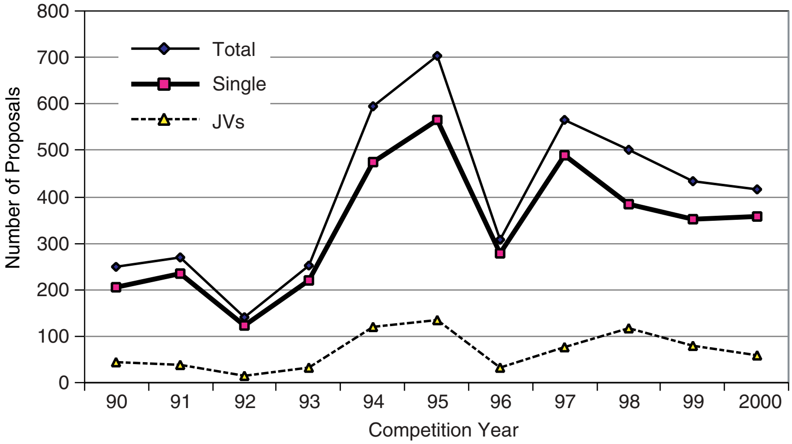

FIGURE 3 ATP proposal submissions, 1990-2000

priate focused competition announcement. A proposal that was screened out at this point was sent to the General Competition's SEB for evaluation. Those that were screened out in any of the Competitions—General, Focused, or Open— due to other serious deficiencies, such as lack of a technical plan, were simply eliminated from competition. Generally about 10 percent have been rejected at this stage, for a wide variety of reasons.

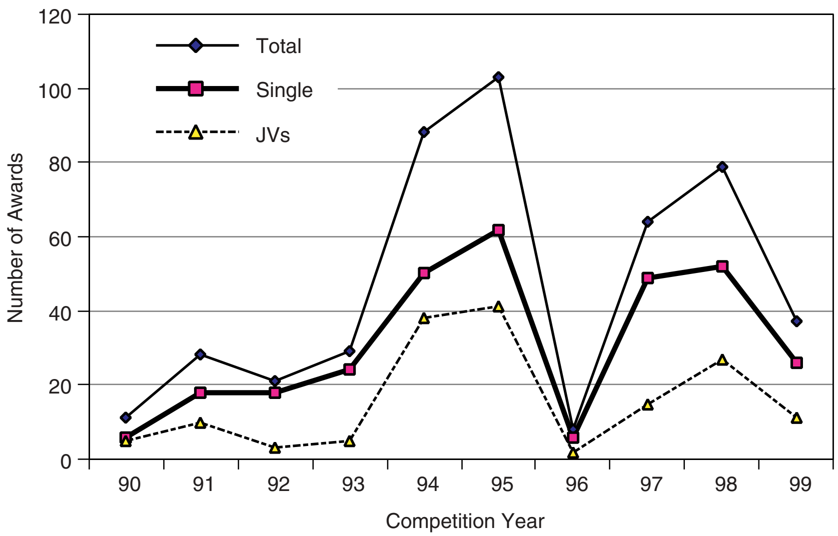

FIGURE 4 ATP awards, 1990-1999

Technical and Business Reviews and Selection

Proposals accepted into a Focused-Program competition went through the same reviews for business and technical merit as entries in General and Open Competitions. However, proposals in Focused-Program Competitions were reviewed in the context of a larger set of pre-planned technical and business goals and with a closer eye to synergy among projects within that program area. Attention to synergy was more difficult in General Competitions which one moment would be considering a biotechnology proposal and the next, a manufacturing technology. Open Competitions have no over-reaching larger program goals, but consideration of a group of proposals in the same technology area makes it more conducive to consider possible synergistic effects.

Outside Independent Reviews

During the first several years of General Competitions, the independent technical and business/economic reviews performed by outside reviewers to provide advice to the SEBs were performed sequentially. All proposals received technical reviews, but only semi-finalists received business/economic reviews by the reviewers outside the SEB. This process was changed to provide technical and business reviews in parallel, regardless of the type of competition, for two reasons: (1) to enable the debriefing process to cover business/economic strengths and weaknesses for all proposals rather than only semi-finalists, and (2) to provide adequate time for business/economic reviews to be conducted.

CHANGES IN THE SUBMISSION PROCESS: OPEN COMPETITION AND ROLLING SUBMISSIONS

In fiscal year 2001, ATP will again hold a major Open Competition. This year will see major changes in the proposal submission processes. The new Director of the ATP, Alan Balutis, introduced modifications to the ATP competition and review process in an effort to streamline the process and reduce the burden on companies submitting proposals. The changes include

- a reduction in the ATP Proposal Preparation Kit by more than 50 percent;
- introduction of "rolling submissions";
- a staged review process;
- the electronic submission of proposals, to be piloted later this year.

Rolling Submissions

The "rolling submission" process allows proposers to submit proposals year round instead of waiting until March (a typical deadline) of the fiscal year to submit proposals. The other major change is in the proposal submission requirements which provides for a multiple stage and sequential review process. This multiple stage process, as illustrated in Figure 5, is intended to reduce the amount of information required at the time of initial proposal submission. Additional information will be requested at later stages of the process as determinations are made that a proposal has high merit. ATP calls these stages in the review process "gates." Under this procedure there are four "gates" from proposal submission to award, as follows:

- Gate 1: Proposer submits detailed information to address the scientific and technological merit selection criterion. Additionally, the proposer submits preliminary information to address the potential for broad-based economic benefits selection criterion. If the information submitted is determined to have high merit ATP notifies the proposer and requests that the required additional information be submitted for consideration in Gate 2.
- Gate 2: Proposer submits more detailed information to address the potential for broad-based economic benefits selection criterion and detailed budget data. If the information submitted is determined to have high merit,

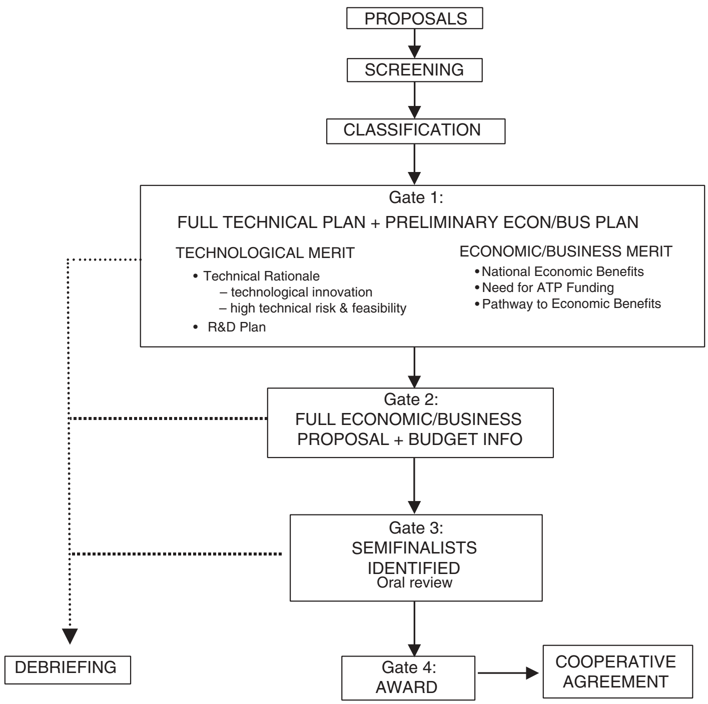

FIGURE 5 Schematic overview of ATP selection process

ATP notifies the proposer of its selection as a semi-finalist and the proposal proceeds to Gate 3.

- Gate 3: The proposer is requested to submit required forms and additional documentation, as necessary, and may be invited to NIST for an oral review. If ATP determines, based on all the information received, that the proposal has sufficiently high merit to be funded, the proposal is considered a finalist and proceeds to Gate 4.
- Gate 4: Final award processing and issuance, if selected.

CONCLUSIONS

Steady Refinement

The ATP has worked steadily to refine the structures of its competitions and its processes for improved management. The past 10 years have seen many adjustments in the proposal review and project selection process, and additional changes are likely as the program staff and management continue to learn from experience and to adjust to the changing requirements of a program focused on rapidly evolving technologies and companies competing in a global marketplace.

Lessons from Evaluation

An additional source of information that is increasingly informing the selection process is ATP's evaluation program. As was noted in the April 2000 review of the program by the National Academies, the ATP benefits from one of the most extensive and intensive evaluation efforts of any federal partnership program. This evaluation effort has produced valuable analysis that sheds light on what is working and what is not. Importantly, these results have been incorporated in the ATP decision process primarily through the training of SEB members and independent reviewers. For example, reviewers are informed about what types of problems to look for when joint ventures are proposed and how through questioning to uncover such problems.

Identifying Long-term Benefits

One important aspect of the training is to look for long-term economic benefits that flow from the project, that is to say, that the value of the project to ATP is evaluated not only on the success of the award recipient but on larger, more diffuse national economic benefits that result from the project. For example, the reviewers look for the use of technology in multiple industries and for the sharing of the technology within the membership of a joint venture. Due to this careful emphasis on long-term economic goals, of the completed projects that have been evaluated to date, 16 percent are demonstrating large returns and approximately 58 percent are demonstrating solid returns.

The Impact of Scale on Operations

Changes in the scale of the ATP have also influenced the choice of operational processes. While requirements in terms of fairness, attention to stakeholder needs, efficiency, and effectiveness have remained constant, changes in operational procedures have occurred. These changes were necessary to allow the capacity of handling in a timely way the number of proposals received in the face of budget-restricted competition cycles. Efforts to achieve processes compatible with larger scale operations, such as implementation of Focused Program Competitions, have in some cases given rise to other problems, such as Congressional objections that the Focused Program selection process was not adequately vetted by outside reviewers in deciding which technologies would be proposed.

The Impact of Uncertainty

The numbers of proposals received are influenced not only by how the program operates, but also, and primarily, by the perceived certainty or uncertainty of its funding levels. The costs that companies incur when they propose to the ATP are certain. However, the available funding for which the firms compete is often perceived as highly uncertain. The ATP is constantly alert for ways to make the program work better for industry in the face of the substantial obstacle of funding uncertainty and its discouraging effects on industry participation. Further changes in the competition structure are, therefore, likely to be made.

How Has This All Worked?

A study just being finalized by the Economic Assessment Office of ATP finds that from a portfolio perspective, the results look strong for the ATP. The estimated net benefits attributed to the program from the top performers alone far exceed the $1.640 billion publicly funded portion of the ATP to date,[7] suggesting that the program is on track to produce a high return for the nation.

REFERENCES

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National Institute of Standards and Technology. ATP web site. http://www.atp.nist.gov.

[7] Because of the matching requirement from the private participants for ATP awards, the total funding of new technologies from the program is approximately $3.3 billion, of which $1.6 is from industry participants. This sum includes 522 projects awarded to 1162 participants and 1045 subcontractors, and involves 172 joint ventures.

Leveraging Research and Development: The Impact of the Advanced Technology Program

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ABSTRACT

This paper examines the factors that affect a firm's chances of winning an award from the Advanced Technology Program (ATP) and the subsequent impact of the award on a firm's success in raising additional funds for its research and development (R&D) activities. Analysis of data from a survey of 1998 ATP applicants shows that proposals with higher ratings by technical and business/economic experts have a greater chance of winning an award in a process that is regarded by winners and non-winners as fair and rational. Further, the projects and firms selected by ATP are more willing to share their research findings with other firms, and tend to be those that open up new pathways for innovation through combining technical areas or by forming new R&D partnerships. Most of the non-winners have not proceeded with any aspect of the R&D project proposed to ATP and, of those that have, most did so at a smaller scale. Furthermore, the ATP award has prestige value for the winning firms; the halo effect from the award increases the success of these firms in attracting additional funding from other sources. Our conclusion is that the ATP is leveraging activities that have a strong potential for broad-based economic benefit.

Acknowledgements: We thank Wesley Cohen, Bronwyn Hall, Frank Lichtenberg, Jeanne Powell, Rosalie Ruegg, Andrew Wang, and Charles Wessner for their detailed comments on earlier drafts of this paper. We are also grateful for the many helpful comments and advice we received from participants at workshops sponsored by the National Academy of Science, the National Bureau of Economic Research, and at presentations at the annual meeting of the American Economic Association and the Western Economic Association.

INTRODUCTION

Through a number of different agencies, the U.S. federal government provides research funding to universities and colleges, government-owned laboratories, and for-profit enterprises. Support for basic research at universities is widely accepted and the links to technical progress are well established. A common question regarding the public funding of research conducted by private firms is if the public interest, specifically the goals of technical advance and economic growth, is being promoted and how. After all, a private firm is expected to fund its own research when it perceives a technical opportunity in an area of its core competency in an established market with reasonable profit expectations.

In some cases, however, private firms may not pursue promising technical opportunities for the following reasons:

- R&D scientific and technical frontiers are risky and the chances of failure are high.[1]
- An individual firm may not have the capabilities required to develop the technology. Complex new technologies may require collaboration and information sharing; however, the cost of establishing research and development partnerships and making them work productively may provide disincentives to undertaking the project.
- Private incentives may not be sufficient to induce a firm to undertake the project in the face of difficulties in appropriating the resulting benefits, i.e., the resulting knowledge may flow to others who receive the revenues from the R&D without sharing the cost.[2]

Public-private R&D partnerships provide a policy instrument that may alleviate these concerns and encourage private-sector investment. A government R&D partnership may provide a catalyst for private firms to undertake research which will have broad-based knowledge benefits for other firms and other industries. Government programs may provide a neutral forum for competitors to work together on mutually beneficial research.[3] In addition, government funding may reduce the cost to the firm of establishing working relationships with R&D collaborators and provide an incentive for firms to undertake partnerships

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[1] A. N. Link et al., "The Economics of Science and Technology, *The Journal of Technology Transfer*, forthcoming, note that the traditional distinctions between basic and applied research have become meaningless in the commercialization of complex technologies. Firms may identify research areas that require additional fundamental research.

[2] Paradoxically, the profit incentive that motivates innovative activity by an individual firm also discourages information sharing and collaborative R&D activities between companies.

[3] An example of productive and profitable research undertaken by public-private partnerships is Sematech. See National Research Council, *Conflict and Cooperation in National Competition for High-Technology Industry*, Washington, D.C.: National Academy Press, 1996, footnote 19.

to blend the firm's capabilities with complementary types of external expertise. Collaboration is also expected to have an additional positive effect on the national economy by facilitating the diffusion of economically relevant knowledge within the private sector, thus further leveraging the public investment. Finally, government R&D funds may reduce the firm's scientific and technical risk sufficiently to bring the project within an acceptable rate of return for private-sector investment.[4]

Recently, governments around the world have encouraged public-private partnerships.[5] The long-term goal of these programs is to achieve greater productivity growth in an economy through the creation of knowledge that may become incorporated in industrial processes, products and services. The logic for public investment is that, in the long run, the economic benefits to consumers, other firms, and the larger national economy will exceed the private returns realized by the firm that received the research award, and thus justify the public investment. In the United States, the Advanced Technology Program provides an example of a government R&D program that attempts to encourage broadly applicable technical advance. Since 1990, the ATP has provided selective cost-sharing awards for early stage industry-defined research projects with broad-based economic potential.[6]

Rationale for Public-Private R&D Partnering

The program mission of the ATP thus depends upon its success in selecting projects with attributes that indicate a high potential to generate substantial economic benefits. Of course, there is no way of guaranteeing, in advance, whether an R&D project actually will result in successful commercialization or if the knowledge created will be valued by other organizations. The ATP's review and

[4] The general argument for government funding of certain types of R&D activities, as articulated by Z. Griliches, "The Search for R&D Spillovers," *Scandinavian Journal of Economics*, 94(Supplement):29-47, is that such subsidies provide an incentive to firms to undertake high-risk R&D projects in which the public rate of return exceeds the private rate of return. This includes, for example, the case where an industry as a whole may benefit from the development of an enabling technology. Private firms typically use some pre-determined benchmark rate of return known as a hurdle rate. The project will only be acceptable if the expected rate of return is above that benchmark. By reducing the cost of the project, government funding will increase the expected rate of return and may make private companies willing to pursue them.

[5] See National Research Council, *Conflict and Cooperation*, pp. 12-40, for a review of international programs that encourage collaboration. For an introduction and review of the objectives of recent U.S. R&D programs see M. R. Kelley, "From Mission to Commercial Orientation: Perils and Possibilities for Federal Industrial Technology Policy," *Economic Development Quarterly*, 11(4):313-328.

[6] For a discussion of the legislation and policy issues that led to the establishment of the ATP see C. Hill, "The Advanced Technology Program: Opportunities for Enhancement," in L. Branscomb and J. Keller, editors, *Investing in Innovation: Creating a Research and Innovation Policy*, Cambridge, MA: MIT Press, 1998, pp. 143-173.

selection process aims to identify high quality research projects proposed by industry that have clearly delineated pathways through which the projects may achieve broad-based economic benefits.[7] High ratings on the technical and economic dimensions by the ATP's reviewers are a pre-requisite for winning an award.

In addition to the assessment of the proposal itself, certain behaviors evident in a firm's R&D strategy may provide an indication of how readily the knowledge generated by the government funded R&D project may diffuse to and benefit other organizations.[8] In particular, a firm that is connected to other businesses for assistance in planning and carrying out its R&D, or a firm that has extensive linkages to the university research community, may offer more opportunity for other organizations to learn about the technical advances from the funded project.[9] Moreover, some firms attempt to guard access to their research results, while others see an advantage in sharing knowledge and are more willing to disseminate their research findings to other firms.[10] Clearly, when a firm openly shares information, the results of its research become known more quickly.

Since the ATP wants to encourage the diffusion of new knowledge by industry, it may favor projects where firms are attempting to forge new ties in new collaborative R&D efforts, or projects proposed by firms that are embedded in networks, or of company R&D and commercial linkages and firms that are more willing to share the knowledge that their R&D creates. The first research question

[7] See the presentation of Rosalie Ruegg, formerly of the ATP and now with TIA Consulting, panel II of the proceedings of this volume, for a description of the direct and indirect pathways of ATP-project impact.

[8] Only when scientific and technical advances become known and are incorporated into new products and processes can ATP expect to see any economic benefits realized from the funded project.

[9] Studies of the strategies that managers use to learn about other organization's products, technologies, and business practices emphasize the importance of both formal linkages between firms and the informal network ties among engineers, scientists, and managers employed in different organizations (e.g.: Y. Doz, "The Evolution of Cooperation in Strategic Alliances: Initial Conditions or Learning Processes?" *Strategic Management Journal,* 17[Summer]:55-83; G. Hamel, "Competition for Competence and Inter-Partner Learning Within International Strategic Alliances," *Strategic Management Journal,* 12[Summer]:83-103; A. C. Inkpen, *The Management of International Joint Ventures: An Organizational Learning Perspective*, London, UK: Routledge, 1995; T. Khanna, R. Gulati, and N. Nohria, "The Dynamics of Learning Alliances: Competition, Cooperation, and Relative Scope," *Strategic Management Journal,* 19[3]:193-210; Walter W. Powell, Kenneth W. Koput, and Laurel Smith-Doerr, "Interorganizational Collaboration And The Locus Of Innovation: Networks Of Learning In Biotechnology," *Administrative Science Quarterly,* 41[1]:116-145). In general, this literature indicates that cooperation among firms is an important pathway for learning about technical advances in other organizations. More specifically, linkages that involve the sharing of resources, whether technical or financial, become important conduits for knowledge transfer among firms.

[10] Paradoxically, in order to gain direct and early access to the knowledge and technologies being developed in other organizations, a firm has to be willing to give some of its own accumulated knowledge and technologies to others. See Julia P. Liebeskind, "Knowledge, Strategy, and the Theory of the Firm," *Strategic Management Journal,* 17(Winter):93-107.

we address in this paper concerns how these differences in R&D strategies of firms are related to winning an ATP award.

- Compared to non-winners, do firms that win an ATP award have R&D strategies with greater potential for diffusing knowledge and incorporating technical advance into commercial applications?

To the extent that the ATP is selecting projects in firms with R&D strategies that are more accessible to other researchers and firms, the more likely it is that the knowledge generated by the project will be taken up and used. Projects with such attributes are more likely to yield economic benefits, all other things being equal, that extend beyond the firm directly engaged in the project.

Leveraging Private Sector R&D Investment

Government funding may also spur additional private investment in R&D activities.[11] For those outside the firm, the value of R&D activities in the early stages of technology development is difficult to assess since there is greater risk and uncertainty.[12] As a result, private investors typically focus on later stage projects. In order to secure private investment, firms must be at a proof of concept phase. Public funding is a means for supporting early stage technology development and moving the project to a point where private investors may be willing to invest.[13] Finally, at any given time, there are a large number of investment opportunities, and it may be difficult for private investors to accurately evaluate potential investments. When information about a company's R&D activity comes from a credible source, such as a government agency with a reputation for scientific integrity as well as programmatic expectations of economic significance, the investment decisions of other organizations may be favorably affected. In light of a large number of potential investment opportunities, the announcement of the ATP award may provide information that certifies an awardee's R&D activities from

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[11] Previous research suggests that the ways in which government provides funding to the private sector is important. Paul A. David, Bronwyn H. Hall, and Andrew A. Toole, "Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence," *Research Policy*, 29:497-529, indicate that the private sector is less likely to increase its own R&D spending when government R&D funding is provided through contract R&D programs in which there is potential for follow-on funding and technology procurement.

[12] See the presentation of David Morgenthaler of Morgenthaler Venture Capital, panel I, of the proceedings of this volume.

[13] See Maryann P. Feldman, Maryellen R. Kelley, with Joshua Schaff and Gabriel Farkas, "Reinforcing Interactions between the Advanced Technology Program and State Technology Programs. Volume II: How The States Assist High-Tech Start-up Companies," NISTIR 6523, June 2000, for an analysis of in-depth case studies that found this relationship. These case studies were used to design this statistical study that we report on here.

the perspective of the investment community.[14] Hence, our second research question focuses on how ATP's funding makes a difference to firms in carrying out the type of high-risk, potentially high payout R&D proposed to the program. We address this question in two parts.

- Do non-winners continue with the proposed research project without ATP funding?
- Does the ATP award induce additional investment by other organizations in the R&D project?

The next section provides an introduction to the ATP and its mission. Section 3 presents the data that we will use to answer our research questions. Section 4 describes how we measure the potential of the project to provide broad-based economic benefits and the basis for our conclusions that ATP is satisfying its mission. Section 5 considers what happened to the non-awarded firms and projects one year later. We conclude that the majority of the non-awardees did not pursue the research. Section 6 considers the effect of the ATP award on the ability to secure additional funding. We conclude that ATP provides a certification function that increases the amount of funds that the firm is able to raise subsequently. This paper concludes by considering the ability of government-funded R&D conducted by private firms to create innovation and potential long-term economic benefits.

SELECTING R&D PROJECTS WITH BROAD-BASED BENEFITS: BACKGROUND ON THE ADVANCED TECHNOLOGY PROGRAM

ATP depends on the initiative of industry to define the goals for the proposed research projects.[15] All applicants are provided a guide to use in preparing proposals. The guide includes information on the evaluation criteria that the ATP

[14] J. Lerner, "The Government as Venture Capitalist: The Long Run Impact of the SBIR Program," *Journal of Business,* 72(3):285-318, suggests that the Small Business Innovation Research (SBIR) program award provides a certification function that informs private investors of a notable opportunity.

[15] The ATP is fundamentally different from other government R&D programs as the focus is industry-defined. This contrasts with the SBIR as a case in point. The SBIR program is a set aside of U.S. Federal Agency funds specifically earmarked for small business. While the program has demonstrated positive effects on the development of new technologies and the growth of the companies, the areas of interest are defined by the agency, not the participating companies. For an overview of the SBIR program and its challenges see National Research Council, *The Small Business Innovation Research Program: Challenges and Opportunities*, Charles W. Wessner, editor, Washington, D.C.: National Academy Press, 1999; and for a review of the operation of SBIR at the Department of Defense see National Research Council, *The Small Business Innovation Research Program: A Review of the Department of Defense Fast Track Initiative*, Charles W. Wessner, editor, Washington, D.C.: National Academy Press, 2000.

employs in selecting awardees. To merit funding, the project must have both scientific and economic potential:

> The research must be challenging, with high technical risk... aimed at overcoming an important problem(s) or exploiting a promising opportunity...[and] must have a strong potential for advancing the state of the art and contributing significantly to the U.S. scientific and technical knowledge base.
>
> The proposed technology must have a strong potential to generate substantial benefits to the nation that extend significantly beyond the direct returns to the proposing organization(s). The proposal must explain why ATP support is needed and what difference ATP funding is expected to make. The pathways to economic benefit...includ[e] the proposer's plan for getting the technology into commercial use, as well as additional routes that might be taken to achieve broader diffusion of the technology.
>
> (*Advanced Technology Program Proposal Preparation Kit*, 1999: 7-8).

Independent technical experts and specialists in the business planning evaluate every proposal. The selection process involves an assessment of the project's contribution to technical advance, its economic potential, and the need for public funding. In any given year, fewer than 20 percent of proposed projects have actually been awarded funding and the overall average is 12%.

STUDY OF THE 1998 ATP APPLICANTS: DATA DESCRIPTION

To assess the ATP program we focus on the competition that was held during the summer of 1998. A total of 502 proposals were submitted. Because ATP guidelines encourage joint projects, there were a total of 822 organizations that applied in this competition. Our primary interest is the 741 for-profit enterprises that applied to ATP in 1998.[16] This group of firms constitutes our sampling frame. The award winners were announced in October 1998.

ATP funded 80 proposals that involved 161 organizations, including 147 for-profit enterprises.

Table 1 shows the distribution of firms by award status and firm size. About 20 percent of all applicant firms received an ATP award in 1998. Small firms, employing fewer than 500 employees, constituted nearly 70 percent of all applicants. Although firms in this size category were only 52 percent of ATP award recipients, they accounted for 83 percent of all awards that were made to individual companies in that year. There were also 27 joint venture (JV) projects funded in 1998. These JV projects include 65 percent of all awardees and 87 percent of the firms with more than 500 employees.

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[16] Private firms must lead ATP projects but there is frequent collaboration with for-profit firms. In 1998 there were 38 universities, 29 non-profit organizations, seven government labs, and seven foreign-owned U.S. subsidiaries.

TABLE 1 Distribution of Applicants by Award Status and Firm Size

	Award Status		
	Award Winners	Non-Winners	All Applicants
Percent of Firms ≥ 500 employees	48%	27%	31%
Percent of Firms < 500 employees	52%	73%	69%
Number of Firms	147 (20%)	594 (80%)	741

To collect data on the 1998 applicants, we conducted a survey on the ATP application process, and the experiences after the ATP application.[17] All interviews were completed over a six-month period (June-December 1999). Our respondent was the person identified as the technical lead for the proposed project. If this person was no longer with the company, we asked to speak to the individual who was most knowledgeable about the proposal and the company's R&D activities in the area identified in the proposal.[18] The telephone questionnaire required 20-30 minutes to complete.[19]

Our sample consisted of 100 percent of the winning firms and a simple random sample of 50 percent of the non-winners. Thus, we contacted 297 non-winners and 147 awardees one year after the 1998 ATP selection process. We completed interviews for 119 winners for an 81 percent response rate (119/147). For the non-winners, we discovered that within one year there were 49 cases that we could not interview, either because the company was no longer in business (23 cases) or because the person responsible for preparing the ATP proposal was no longer employed at the company and the company was not pursuing any aspect of the R&D proposed to ATP (26 cases). We adjusted our response rate accordingly. We completed interviews for 122 non-winners, for a 50 percent response rate (122/[297-49]). This yields an overall effective response rate of 61 percent.

[17] The survey instrument was reviewed and approved by the Office of Management and Budget and the JHU Committee on the Use of Human Subjects. OMB granted approval (no. 0693-0027) for Johns Hopkins University to conduct the survey on 24 March 1999.

[18] Prior to calling our respondents to conduct the interviews, we followed standard survey method procedures, sending a letter to all potential respondents in the selected sample to explain the purpose of the survey, identify ATP as the sponsor of the study, and asked for cooperation. This letter also contained a statement of confidentiality and assurance that responses to any of the survey questions would remain anonymous, and would not be publicly released in any form that would identify a specific individual or company. The letter included a list of questions that the respondent might find helpful to have in advance of the telephone interview. In addition, our mailing included an introductory letter from the ATP. The Schaefer Center for Survey Research at the University of Baltimore conducted the telephone interviews.

[19] A copy of the questionnaire is available from the authors upon request.

The survey results were matched with company and project-specific data from other sources. First, we used independent sources such as the CorpTech Database and Hoovers Online Company and Industry Network to verify survey responses concerning employment, financing, and the founding date of the company.[20] Second, we matched each record with information from ATP administrative records on the technology area of the proposal, the results of the ATP proposal review process, and the firm's prior history of applications and awards.

PATHWAYS TO INNOVATION: VALUATING THE POTENTIAL FOR BROAD-BASED TECHNICAL ADVANCES AND ECONOMIC GROWTH

A project may have greater economic potential if the firm embarks on a new technical problem or forms a new R&D collaboration. Although R&D collaborations are widely recognized as an important strategy for learning about technical advance,[21] establishing new collaborative relationships is especially difficult and costly for firms.[22] Table 2 shows the percent of projects proposed to ATP in 1998 that involved two or more organizations as research partners, and the percent of new partnerships and new technical areas proposed by ATP award winners compared to non-winners. Seventy-nine percent of the 1998 ATP applicants in our sample included other organizations in their proposal. There is no difference between award winners and non-winners in their propensity to have partners. However, the percent of award winners identifying a new collaborator, as their most important research partner is much higher compared to non-winners (59 percent versus 42 percent). Award winners were also more likely to propose a project in a technical area new to the firm (47 percent versus 19 percent).

One firm's R&D activities may have the potential to augment other firms' innovative capabilities but only if research results and knowledge are shared. Competitors' reluctance to collaborate and share research results may be likely, however, for certain complex technical areas sharing information may be essential for firm's technical advance. Moreover, an award winning firm's willingness to diffuse research results affords a greater opportunity for other firms to benefit from government funded research.

As indicated in Table 3, we used three statements about the company's approach to construct a measure of the firms' tendency towards either openness or secrecy in conducting its own R&D. The possible scores ranged from 0 to 3. We

[20] See http://www.corptech.com/ and http://www.hoovers.com/.

[21] For recent research on the advantages of collaboration see Doz, "The Evolution of Cooperation"; Hamel, "Competition for Competence"; Inkpen, *The Management of International Joint Ventures*; Khanna, Gulati, and Nohria, "The Dynamics of Learning Alliances"; Powell, Koput, and Smith-Doerr, "Interorganizational Collaboration."

[22] K. R. Harrigan, "Joint Ventures and Competitive Strategy," *Strategic Management Journal,* 9(March-April):141-158.

TABLE 2 Indicators of the Creation of New Pathways to Innovation

New Partnerships	
Percent of 1998 applicants who included other organizations in the ATP proposal	79%
If Yes, was this a new partnership?	
Award winners	59%
Non-winners	42%
New Technical Area	
Percent of applicants proposing a project for which it did not have a prior plan—a technology new to the company:	
Award winners	47%
Non-winners	19%

TABLE 3 Tendency Towards Openness or Secrecy

Willingness to make research results available to other firms:	
To what extent do you intend to make your research results available to other firms and industries?	1 = almost always or sometimes; 0 = rarely or never
Do you think that keeping your company's R&D knowledge from spreading to other firms is important to your firm's long run success?	1 = no; 0 = yes
Would you ever consider not engaging in new R&D activity because you believe another firm may benefit from it?	1 = no; 0 = yes

expect that most firms will have a tendency to secrecy.[23] Firms that answered yes to two of the three questions were considered to exhibit a willingness to share research results.

The potential for contributing to scientific and technical advance may be enhanced by a firm's linkages to universities and other institutions. For example, universities are an important source of new knowledge that may be applied to a broad range of industrial problems (Mowery and Rosenberg, 1989). In carrying out R&D a firm may draw upon it connections to university faculty, graduates,

[23] For a discussion of the importance of secrecy in R&D strategies see R. R. Nelson, "Capitalism as an Engine of Innovation" in *The Sources of Economic Growth*, Richard R. Nelson, editor, Cambridge and London: Harvard University Press, 1996. pp. 52-83., and Julia P. Liebeskind, "Keeping Organizational Secrets: Protective Institutional Mechanisms and their Costs," *Industrial and Corporate Change,* 6(3):623-663.

laboratory facilities, and intellectual property to augment its internal capabilities. These relationships are also potential pathways for reciprocal knowledge flows from the firm to the university-based research community and then perhaps on to other firms. The more connections that a firm has to university resources, the greater the potential for knowledge flows in both directions. Our survey used twelve indicators of the firm's connections to universities (see Table 4).[24] Included are universities as R&D partners in general and as resources for the ATP project specifically. The combination of the two sets of measures serves as an index of the strength and diversity of connections to the university-based research community.

The ATP mandate stresses commercial and economic benefits as program goals; however, the program does not fund product development or market research. As a consequence, the potential of a technology to attract non-ATP resources for commercialization is critical. This could take the form of additional private capital attracted by the ATP awarded company, or might include resources provided by other companies who take up the technology and incorporate it into their commercial efforts. Connections to other firms, in the planning and development of the project, and more generally, as sources of financial and technical support, may be especially important to the commercialization potential and eventual impact of the project on the economy. We asked about applicant's connections to other firms in preparing the proposal for ATP, as potential collaborators on the project, and more generally, in providing technical and financial resources to the applicant in the two years prior to the application. We used the 19 questions shown in Table 5 to construct a business linkage index. A higher number of links to other businesses signals connection to a diversity of resources particularly important for companies seeking to commercialize their technologies.

ATP Awards Risky Projects with the Potential for Broad-based Economic Benefits

We find that the ATP awarded those companies who proposed projects involving the formation of new partnerships and new areas of research for the firm. When compared to unsuccessful applicants, the firms that were awarded by ATP were more likely to have extensive linkages to other businesses and to profess a greater willingness to share information about their research findings with other firms. This indicates that they had both the linkages and the inclination so that broad-based economic benefits might be realized. Surprisingly, we find no statistical difference between winners and non-winners in the extent of their linkages to universities.[25] That suggests that the 1998 ATP award winners do not differ, on

[24] See Feldman and Kelley, "The Case for Government R&D Additionality," for further discussion.

[25] The average applicant scored 5.45 on the university linkage index with no statistical difference between award winners and non-winners.

TABLE 4 Questionnaire Items in University Linkages Index

UNIVERSITY LINKAGES INDEX

Number of Connections

(Number of 'yes' answers to the following questions)

For ATP project and proposal:

1. Did your company first learn about ATP from someone at a university?
2. Did a university help you identify the research partner you consider to be the most important for the project you proposed to ATP?
3. In preparing the technical plan portion of your proposal, did you get assistance from someone at a university?
4. In preparing the business plan portion of your proposal, did you get assistance from someone at a university?
5. [If technical lead on the ATP project has been employed with the company less than 5 years], was this person previously employed at a university?

General R&D connections to university resources:

6. Does your company have any contracts or licensing agreements for intellectual property at universities?

In the two years prior to your ATP application have you used assistance from a university program

7. to address a technical problem?
8. to prepare a business or marketing plan?
9. to recruit R&D employees?
10. In the two years prior to your ATP application have you formed an alliance with a university to address your needs for equipment and facilities?
11. In the two years prior to your ATP application have any of your R&D personnel attended training or technical programs sponsored by a university?
12. In the two years prior to your ATP application, for your R&D or technology development activities, has your company received funds from a university program?

average, from non-winning applicants, on the extent of their ties to the university-based research community. Given the types of projects that were proposed to the ATP, it is perhaps not surprising that we find that all applicants had links to universities.

We expect that proposals that receive a high rating by technical and business/economic reviewers to have a greater chance of winning an award. Our results indicate that on both dimensions, the higher the rating the proposal received by reviewers, the greater the chances of the project winning an award. However, having a high quality proposal was not the only criteria. We find that the following attributes increase the likelihood of winning an ATP award:

- riskier research projects that are new to the firm;

TABLE 5 Questionnaire Items in Business Linkages Index

BUSINESS LINKAGES INDEX

Number of Connections

(number of 'yes' answers to the following questions)

For ATP project and proposal:

1. Did your company first learn about ATP from: a consulting firm, someone at another company, or a venture capitalist?
2. Did a venture capitalist help you identify the research partner you consider to be the most important for the project you proposed to ATP?
3. In preparing the technical plan portion of your proposal, did you get assistance from a consulting firm?
4. In preparing the technical plan portion of your proposal, did you get assistance from someone at another company?
5. In preparing the business plan portion of your proposal, did you get assistance from a consulting firm?
6. In preparing the business plan portion of your proposal, did you get assistance from someone at another company?
7. [If technical lead on the ATP project has been employed with the company less than 5 years], was this person previously employed at another company?

Other Business Ties:

In the two years prior to your ATP application have you used assistance from a private venture capital firm

8. to address a technical problem?
9. to prepare a business or marketing plan?

In the two years prior to your ATP application, has your company received financing for your R&D or technology development activities from

10. a private venture capital fund?
11. an individual (angel) investor?
12. another company?

In the two years prior to your ATP application, to address your needs for equipment and facilities, has your company used

13. private investor or angel financing?
14. venture capital financing?
15. secured bank financing?
16. an alliance with another company?

In the two years prior to your ATP application have you used assistance from a private consulting firm

17. to address a technical problem?
18. to prepare a business or marketing plan?

19. In the two years prior to your ATP application have you used assistance from another company to address a technical problem?

- research projects that form new R&D partnerships between organizations;
- firms that demonstrate a tendency towards openness in communications about research with other firms and institutions; and
- firms that have a more extensive set of business-to-business linkages.

These attributes distinguish award winners from other applicants.

Our model included controls for whether the applicant had applied to ATP in the past, the number of times the applicant won an ATP award, the technical area of the proposed R&D project and the relative cost, as a measure of effort, in preparing an ATP proposal. We might expect that companies that have applied or won previously might have an advantage over applicants that have no prior experience with ATP. In addition, the cost of preparing a proposal ranged from $2,000 to $300,000 with a median of $15,000 per firm and we might expect that a professionally presented proposal might affect award status. Our regression results do not find any support that experience with the ATP matters nor do we show that proposal preparation cost is related to winning, independent of other attributes of the project.

We conclude that ATP is selecting projects with greater potential for contributing to other firms' R&D efforts and technology use. Award winning projects and firms have attributes that suggest a greater chance of contributing knowledge to other organizations and thus advancing the technical frontier. Moreover, award-winning firms proposing these projects have greater potential for achieving an economic impact through connections to the resources of other firms and their potential support of the further development and deployment of the technologies.

ONE YEAR LATER: WHAT HAPPENED TO NON-WINNERS AND THE R&D PROJECTS THEY PROPOSED TO THE ATP?

More than a year passed between the ATP proposal submission and the time we contacted firms to conduct our survey. During the review and selection process, the ATP attempts to determine whether or not the R&D activity that is being proposed is likely to be carried forward at the same speed and scale by the company without any assistance from the ATP. Hence, if ATP attracts proposals that companies would proceed with anyway at the same funding level, with the same timeframe and goals, we would expect to see a high proportion of non-winning projects proceeding during this period of time. An important consideration in the proposal evaluation decision is an assessment of whether the project is likely to proceed without government funding. However, as Table 6 indicates, that is not the case.

If a project is believed to be of central importance to a firm that has already funded this type of R&D from its own resources, the ATP is likely to reject the proposal. Similarly, if a company has access to other funding sources (within or outside the firm), the ATP may choose to award its scarce resources to firms that lack access to such funding sources.

TABLE 6 The Extent to Which Non-Winners Pursue the ATP Proposed R&D Project Without ATP Funding

Did not proceed with the project, at any scale	62%
Began project on a *much smaller scale* than proposed to ATP	17%
Began project on a *somewhat smaller scale* than proposed to ATP	12%
Began project at about the *same scale* as proposed to ATP	5%
Began project on a *somewhat larger scale* than proposed to ATP	3%
Began project on a *much larger scale* than proposed to ATP	1%
Number of Cases	168

Note: Three respondents were unable or refused to answer this question.

More than three-fifths of the non-winners (62 percent) have not proceeded with any aspect of the R&D project that they proposed to ATP. This number includes the non-winners that we discovered had gone out of business in the past year. Also included are the projects where the persons responsible for preparing the proposal no longer worked for the company and there was no one whom we could identify who knew about the proposal or any continuation of that work in the same technical area.[26] In addition to these 49 cases, there were another 66 non-winners who indicated that, in the past year, their company had not proceeded with any aspect of the project proposed to ATP.

Nearly 37 percent of the non-awardees began work on the proposed project at some level of effort. However, in most instances (77 percent), the project was pursued at a smaller scale than the company had proposed to the ATP. Only five percent of the firms that received no funding from ATP were proceeding at the same scale as they had originally proposed the previous year, while less than four percent of the non-winners were proceeding with a larger scale effort than had been proposed to ATP. These results suggest that, for the most part, ATP is attracting applicants that need support in order to proceed with their R&D plans. A small minority of non-winners pursued its R&D plans at the same or an even greater scale than originally proposed to ATP. It seems reasonable to assume that the few non-winners who proceeded at the same or greater scale than they had proposed to the ATP were rejected because the ATP saw no need to fund these projects: the projects were promising but the need for public funding was not apparent.

[26] In most respects, the projects for firms that either went out of business or where the P.I. (Principal Investigator) was no longer employed at the firm were similar to the other non-awardees. However, we found one important difference. When compared to the evaluation of their business plans, the defunct firms were rated as having stronger, on average, technical plans. This suggests that they were relatively weaker on the business front.

HALO EFFECT: DOES THE ATP AWARD INCREASE R&D FUNDING FROM OTHER SOURCES?

When an enterprise first wins an R&D contract from a government agency the award may be a signal to non-government sources of funding, such as banks, venture capital firms and other potential investors, that the firm has a potential future stream of revenue from a reliable customer (the U.S. government). The ATP awards differ from the usual government R&D contracts to industry, and hence the economic information conveyed by the award is quite different. There is no promise of follow-on funding by the agency. The ATP seeks to fund R&D projects that have commercial applications, and there is no procurement connection—the ATP does not purchase the technology it helps to develop through its awards. In light of the unique features of the program, we assess the potential influence of an ATP award on the subsequent behavior of the investment community to arise from the information the award signifies about both the technical and economic potential of the project and firm.

For an ATP award to influence the subsequent decision of other sources of research funding implies that the announcement of the award itself provides valuable and credible information to the investment community. The host agency of the ATP is the National Institute of Standards and Technology (NIST), which is widely recognized to be an important source of technical information and expertise in a number of areas. Yet in order for the ATP to benefit from the prestige of NIST, and for the awards to signify quality or merit, the selection process itself must be perceived as fair and rational (i.e., explainable in relation to the criteria). Our survey provides evidence that the ATP selection and award process is widely viewed as fair and rational.

Applicants' Perceptions of the Selection and Award Process

The ATP emphasizes the impartiality of its treatment of proposals during the review and selection process. We asked award winners and non-winners alike about their perceptions of the selection process and whether the respondent believed that his/her company would consider applying to ATP in the future. Tables 7 and 8 present the responses to these questions by the award status of the respondent.

As we would expect, Table 7 shows that a high percent (95 percent) of those that won an ATP award perceived the selection and review process to be fair.

TABLE 7 Overall, Regardless of the Outcome for Your Proposal, Did the ATP Review and Selection Process Appear Fair?

	Award Status		
	Award Winners	Non-Winners	All Applicants
Yes	95%	67%	81%
No	5%	33%	19%

TABLE 8 To Your Knowledge, Does Your Company Plan to Apply to the ATP in the Future?

	Award Status		
	Award Winners	Non-Winners	All Applicants
Definitely/Very likely	82.0%	59.0%	70.0%
Undecided	15.0%	12.0%	13.0%
Not very likely/Definitely not	4.0%	29.0%	17.0%

However, among non-winners, a substantial majority (67 percent) also considered the review and selection process to be fair. These responses suggest that ATP has a reputation for fairness that is widely recognized. As further evidence, consider the responses to the question about the respondent company's plans to apply to ATP in the future shown in Table 8. Although there is a higher negative response from non-winners, a majority (59 percent) is very positive about the prospect of applying to ATP again.[27]

When a company fails to win an award, the ATP provides the opportunity for these companies to discuss with panel representatives both the strengths and weaknesses that were identified in the proposal during the review process. Once a company, or group of companies, has been notified that the project was not selected for funding, its management may request to schedule a telephone debriefing session with ATP within a few weeks of the decision. Although there are usually two representatives from the ATP's expert panels (a business and a technical expert), as many individuals from the project as the companies wish may participate in the debriefing.

Table 9 shows that the majority of non-winners who responded to our survey, 63 percent, indicated that they had participated in a debriefing in 1998. In addition, we include their assessments of the value of the feedback they received from their discussions with ATP staff during the session. In general, most non-

TABLE 9 Percent of Non-Winners that Participated in a Debriefing and Respondents' Assessment of ATP's Helpfulness to the Company

Percent of non-winners who participated in a debriefing from ATP staff	63.1
How helpful did you find the debriefing session to be?	Percent "yes"
very helpful	31.9
reasonably helpful	37.0
not sure	2.6
not particularly helpful	19.4
not at all helpful	9.1

[27] Note that the percent of winners and non-winners that are undecided is about the same (15 percent of winners compared to 12 percent of non-winners).

awardees (69 percent) found the debriefing either to be very helpful (32 percent) or reasonably helpful (37 percent). These responses suggest that most non-winners perceived the ATP staff's explanation for rejecting the proposal to be rational and to provide useful guidance for improving the firm's technical and/or business planning.

Pursuing R&D Funding from Other Sources: The Impact of the ATP Award

The highly selective and competitive nature of the ATP award may signal potential investors about the quality of the firms' R&D project. As a result, other investors such as private angels or venture capital, other businesses, as well as state governments and other federal agencies, may invest in the firm. We may expect the ATP awards to confer a halo effect to winning firms and projects, boosting the chances of a firm's success in attracting additional funding for its R&D activities.

To test for this effect, we considered the group of applicants that pursued other funding sources in the year following the ATP application. Table 10 compares the percentages of firms in the two award status categories that sought additional funding from other sources and the percentages that actually succeeded in attracting funding from these sources. Although a minority of all applicants sought funding from other sources, the percentage of ATP award winners seeking additional funding was much lower. On average, however, the ATP awardees who sought funding from other sources were much more successful in attracting funds than non-winners. We asked firms about the amount of funding that they received for the ATP-proposed research project from non-ATP sources, including private individuals, venture capitalists, other firms, state and local government programs, and other federal government agencies.

TABLE 10 Percentage of Firms that Applied to Other Funding Sources to Support Their R&D Activities and Their Success Rates by ATP Award Status

	Award Status		
	Award Winners	Non-Winners	All Applicants
Percent of all firms in award category that applied to other funding sources	25	47	38
Percent of those firms seeking funding that succeeded in attracting additional investment for their R&D activities	73	33	44

The ATP Halo Effect

In order to determine if the ATP award has the hypothesized halo effect and how much it might be worth in additional funds, we took into account other factors related to winning an ATP award that may also influence other investors.[28] These include the firm's prior success in raising funds, the size of the firm, and the maximum rating by the ATP reviewers. The reviewers' ratings serve as a measure of the technical quality and promise of a project and of the business and economic potential of the technology. We are interested in determining the influence of the ATP award as a pure signal to the investment community, and our statistical analyses confirm our hypothesis. After we have controlled for these other factors, we still find a significant halo effect from an ATP award.[29] Award winners who seek additional funding from non-ATP sources were more successful than non-winners and received a larger amount of funding.

Our analysis concludes that winning an ATP award significantly increases the firm's success in attracting additional funds from other sources for R&D activities. Our findings provide strong evidence that the ATP award confers a halo effect on winners that makes them more likely to attract other funding when compared to non-winners of the same size, and age with project of similar business and technical quality. Thus, our results confirm that the ATP award appears to send a market signal that certifies that the firm and the technology are promising.

LEVERAGING R&D: THE POTENTIAL OF THE ATP

Growth theorists describe two roles for government R&D policy.[30] The first role is in funding the supply of R&D. Most research to date has focused on this topic. The second role for government is providing incentives for private sector R&D and generating a set of behavioral responses that would be expected to stimulate R&D and promote innovation and economic growth. We know the most about the supply of R&D resources. Less is known about the ways in which government programs provide incentives for activities that generate innovation and economic growth.

In this paper, we have shown how a government program is leveraging private sector R&D activities by selecting projects with greater potential for diffus-

[28] We used a TOBIT model to estimate the total amount of funding a firm succeeded in raising from a number of different sources. The TOBIT model accommodates the truncated nature of the dependent variable that has a lower bound of zero. See Feldman and Kelley, "The Case for Government R&D Additionality," for details.

[29] Not surprising, we find that prior success in raising funds matters. The greater the amount of funding a firm was able to raise in the past, the more success it will have in obtaining additional funding. We also find that smaller firms were more successful in raising additional funds.

[30] Boyan Jovanovic, "Growth Theory," NBER Working Paper no. 7468, 2000.

ing knowledge and for contributing to the development of new technologies for commercial use. In essence, the mission of the Advanced Technology Program is to support private sector R&D projects that offer potential for contributing to technical advance and for realizing economic value. Our findings suggest that the operation of the program is consistent with its mandate and objectives. While the program is selecting projects that are rated highly by independent technical and business experts, it awards technically risky, new projects proposed by firms that have strong external linkages to other institutions and exhibit a willingness to diffuse knowledge based on their research findings.

We conclude that ATP is selecting projects and firms that have greater potential for increasing the circulation of new knowledge and for having the business connections necessary to realize economic benefits from its activities. The extent of a firm's linkages to other enterprises and to the resources of universities indicate that a firm is well-positioned to both tap the capabilities of other actors in our nation's innovation system and be a conduit for carrying the knowledge generated by an ATP project to use by other firms. These types of connections are important to the overall operation of the entire U.S. innovation system. We also find that the ATP supports the formation of new linkages and the initiation of R&D projects that bridge different technical areas, opening up new pathways to innovation.

We provide evidence that the investment community values the ATP award. Among firms that seek additional funding, we find that ATP award winners are more successful than non-winners. The halo effect from the ATP award is independent of the ratings of the quality of the project, and the firm's prior success in winning funds from these sources. Since few R&D projects proposed to ATP actually proceed at a comparable level, we conclude that the ATP is stimulating additional investment in risky R&D projects that would otherwise not be funded by the firms themselves or other funding sources.

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Estimating Economic Benefits from ATP Funding of New Medical Technologies[1]

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OVERVIEW

An Evaluation Framework

This study develops a project evaluation framework based on economic principles and uses it to conduct a set of case studies of seven tissue-engineering projects funded by the ATP between 1990 and 1996. Tissue engineering offers the potential of better medical treatments at lower cost. Included in the study are new technologies for the diagnosis and treatment of cancer; the treatment of diabetes, damaged ligaments, tendons, and articular cartilage; and transplanting xenogenic organs.

Estimating Technology Benefits

The economic benefits of new medical technologies include any reductions in the direct costs of medical treatment, and, reductions in morbidity, mortality, and patient pain and suffering. The method incorporates a counterfactual scenario with "defender technologies"—to model the situation without ATP funding—for

[1] This paper summarizes a substantial study of seven ATP-funded tissue-engineering projects published as *A Framework for Estimating the National Economic Benefits of ATP Funding of Medical Technologies*, NIST GCR 97-737, led by Dr. Sheila A. Martin. This report is available on the ATP website at http://www.atp.nist.gov/eao/eao_pubs.htm. Dr. Martin has since left RTI and is now an executive policy advisor to the governor of the state of Washington. Appreciation is extended to Rosalie Ruegg for her counsel and support.

comparison with the situation with ATP funding. Three measures of benefit are computed for each project: (1) social return on investment, (2) private return on investment, a component of social return, and (3) social return on public investment, the return on ATP's investment based on the difference in social return with and without the ATP.

Findings: Large Social Spillovers

All the projects have expected social returns much larger than their private returns, primarily due to projected positive spillovers to patients treated with the new technologies. ATP played a significant role in increasing the expected returns on these projects to the developers and to society at large by accelerating the R&D phase of the projects and improving the probability of technical success. The estimated composite social return on ATP's investment in the seven projects is $34 billion, in net present value.

Limitations

Our methodology and its use to evaluate the seven projects have limitations. Modeling the entire process from R&D to health outcomes requires the development and use of a large amount of data. In some cases, the data is directly estimated. In others when data are lacking, assumptions must be employed. Thus, the findings are preliminary. Despite limitations, this approach does provide a useful framework for evaluating ATP's expected contributions to social welfare.

EVALUATING MEDICAL TECHNOLOGIES

The objective is to provide insight regarding the factors that affect the social return on public investment in ATP-funded projects with medical applications. ATP-funded medical technologies may improve the long-run health outcomes of thousands of patients each year with acute and chronic diseases. They may also reduce the cost of health care. Valuing these effects requires extending conventional benefit-cost models and applying methods commonly used in health economics. We developed a framework for measuring benefits resulting from improved patient health, reduced cost of medical care, and creation of new business opportunities for the technical innovators and their partners.

We also demonstrated the feasibility of our approach by applying the methodology to seven ATP-funded technologies in tissue engineering. Tissue engineering integrates discoveries from biochemistry, cellular and molecular biology, genetics, material science, and biomedical engineering to produce materials and techniques that can be used either to replace or to correct poorly functioning components in humans or animals. At the time of the study, the seven projects examined comprised all of the tissue engineering projects funded by the ATP;

hence, it provided comprehensive coverage of projects funded in the technology area.[2]

This paper describes RTI's general approach to assessing the impact of ATP funding on medical technologies. It also briefly describes the seven tissue-engineering projects funded by the ATP, and outlines RTI's procedures for conducting case studies of the seven projects. It reports the results of the analysis, with an emphasis on the social benefit attributed to ATP funding.

THE ATP-FUNDED TECHNOLOGIES

Table 1 lists the seven projects. The first four projects received more of the effort and resources because better information about potential impacts of the technology and the costs of development was available for them.

Aastrom Biosciences sought to develop a laboratory-scale prototype bioreactor that can culture and grow large numbers of human stem cells from a few. This technology would greatly reduce the invasiveness, inconvenience, costs, pain, and risks of bone marrow transplant (the focus of our evaluation), and it has other potential applications as well.

Integra LifeSciences' project sought to develop a novel synthetic polymer for creating new bioabsorbable materials, free of toxins, for use in biomedical implants. The technology has broad applications in orthopedics (fracture fixation, cartilage and ligament repair), wound care, cardiovascular repair, and drug delivery. Use of biomedical implants made from the material is expected to minimize or eliminate the need for second surgeries to remove implants, eliminating the costs and risks of such surgeries and possibly reducing the likelihood of secondary fractures. Our evaluation focused on the first expected application, nonweight-bearing pins and screws for fracture fixation.

BioHybrid Technologies' project was to develop the capability to implant encapsulated cells from pig embryos into the human body to produce hormones or other bioactive agents that the patient cannot produce at all or not in sufficient quantities. The approach is to encase the cells in microspheres with pores large enough to permit glucose, nutrients, electrolytes, oxygen, and relatively small bioactive species, like insulin, to pass through, but small enough to block the larger immunocytes and other relatively large molecules involved in transplant rejection. The "microreactor" technology has the potential for therapeutic applications to diabetic patients (the focus of our evaluation), as well as to those with Parkinson's disease, Alzheimer's, and other diseases. If successful, the technology would substitute for a functioning pancreas and would virtually eliminate many of the risks of long-term complications resulting from diabetes.

[2] Subsequently, ATP organized a Focused Program in Tissue Engineering and a number of additional tissue-engineering projects were funded. A description of the Focused Program and a listing of all tissue engineering projects funded through the present time can be found at the ATP website: http://www.atp.gov.

TABLE 1 Projects Included in This Study

ATP Project Title	Project Sponsor	ATP Award: Competition No.	ATP Award: Duration	ATP Award: Funding Level
In-Depth Case Studies				
Human Stem Cell and Hematopoietic Expansion Systems *"Stem Cell Expansion"*	Aastrom Biosciences, Inc.	91-01	2 years	$1,220,000
Structurally New Biopolymers Derived from Alpha-L Amino Acids *"Biopolymers for Tissue Repair"*	Integra LifeSciences Corporation	93-01	3 years	$1,999,000
Disease Treatment Using Living Implantable Microreactors *"Living Implantable Microreactors"*	BioHybrid Technologies Inc. (lead company in joint venture)	93-01	3 years	$4,263,000
Treatment of Diabetes by Proliferated Human Islets in Photocrosslinkable Alginate Capsules *"Proliferated Human Islets"*	VivoRx, Inc.	94-01	3 years	$2,000,000
Brief Case Studies				
Fabrication Using Clinical Prosthesis from Biomaterials *"Biomaterials for Clinical Prostheses"*	Tissue Engineering, Inc.	92-01	3 years	$1,999,000
Application of Gene Therapy to Treatment of Cardiovascular Diseases *"Gene Therapy Applications"*	Progenitor, Inc.	94-01	3 years	$1,996,000
Universal Donor Organs for Transplantations *"Universal Donor Organs"*	Alexion Pharmaceuticals	95-01	3 years	$1,999,000

VivoRx's project was similar to BioHybrid's in terms of objective, but differed in terms of approach.[3] VivoRx's focus was on developing culture conditions and methods for proliferating human islet cells for encapsulating in an immunoprotective membrane for transplantation into diabetes patients (the focus of our evaluation). It also has potential therapeutic applications for liver disease, thyroid disease, Parkinson's disease, and Alzheimer's disease.

Tissue Engineering, Inc.'s project developed animal-derived extracellular matrix (ADMAT) material that when used to repair damaged or dysfunctional tissues and organs in the body would induce the body's own cells to rebuild the lost tissue. ADMAT, which can be spun and woven into fibers, or formed into films, foams, and sheets, provides an ordered, three-dimensional structure that can be used to support tissue regeneration. Its intended uses are to develop scaffolds for vascular grafts, ligaments, tendons, periodontal tissue, and similar reconstructions, and, ultimately, as a matrix on which "glandular" cells can grow and function. Our evaluation focus was on an early-expected use of ADMAT, for repairing the anterior cruciate ligament (ACL) in the knee.

Progenitor's project was originally focused on exploiting the versatility of primitive stem cells as the basis for treating a range of ailments anchored in endothelial cells, which form blood vessels making up the circulatory system. To a lesser extent, the project was to focus on cancer treatment and bone development. In the course of its research, Progenitor discovered a molecule that plays an important role in the growth, differentiation, and proliferation of endothelial cells, expected to lead to new treatment for solid tumor cancers. The first planned application of the discovery (and the focus of this evaluation) is the diagnosis, location, and staging of soft tissue cancer metastases. The resulting improvement in diagnostic techniques will allow for more aggressive, effective cancer therapy at an earlier stage of metastasis, improving patients' prognosis. Because currently no technologies can image soft tissue adequately to diagnose metastasis at a very early stage, Progenitor's technology will not replace current technologies, but rather will add to current diagnostic techniques.

Alexion Pharmaceuticals' project to develop xenogenic transplants—transplants from other animals to humans—offers an approach to solve the severe shortage of donor organs for transplantation. Hyperacute rejection generally causes xenogenic transplants to fail within minutes to hours. By developing transgenic pigs that express key human genes, Alexion would eliminate the rejection of the organs transplanted in humans. The resulting availability of suitable organs for transplant would eliminate the long waiting times with their associated negative medical effects; would allow surgeries to be scheduled optimally; would reduce or eliminate the cost of maintaining a recipient in the hospital while await-

[3] We did not account for competitive or synergistic effects among the seven technologies in computing the composite measures.

ing a donor organ; and would eliminate the need to keep donors alive on life support until the removal surgery can take place.

ANALYTICAL APPROACH

The methodology takes a very detailed and specific look at the entire R&D-commercialization-production-health process for each technology by linking these stages together in a techno-economic framework. The approach is to model the probability of key outcomes with and without ATP support. We begin with an analytical approach recommended by Mansfield[4]—essentially a benefit-cost framework—and modify it to handle some of the special features of medical technologies. Most notably, we use nonmarket methods to value the expected improvements in the health of individuals with acute and chronic diseases who could be benefited by the technologies.

The economic burden of illness and disease potentially includes (1) direct medical costs in the form of explicit payments for prevention and treatment; (2) indirect costs in terms of productivity losses and the implicit value of the resources expended by uncompensated caregivers; and (3) intangible costs, comprising the pain and suffering incurred by patients and patient' families and friends. Our study focuses on (1) direct medical costs and (3) the intangible costs, and excludes (2) indirect effects.

Creating a Counterfactual

Central to evaluating ATP's contribution to the technologies and to social welfare is the need to create a "counterfactual," that is, a hypothesized (unobserved) characterization of the world simulating how the economy and patient well-being would have been without ATP support for the technology. In developing a counterfactual, we follow a long tradition in economics of using such an approach to address public policy and technology issues. It is a practice considered fundamental to economic evaluation. We model and compare a future world without ATP support of the medical technologies to one with ATP support. To do this, we explicitly characterize the R&D, commercialization, production, and patient application phases of each technology, and also the defender technology, that is, the expected best alternative treatment that would be used if the ATP-funded technologies were not made available. The comparison nets out the effects of the alternative, displaced technologies.

Rational R&D Decisions

Companies are assumed to pursue R&D because, if successful, the outcome provides a stream of profits in the future. Our approach is to mimic the rational

[4] E. Mansfield, *Estimating Social and Private Returns from Innovations Based on the Advanced Technology Program: Problems and Opportunities*, NIST GCR 99-780, January 1996.

R&D decision-making process of entrepreneurs and see how ATP is likely to affect the process and its outcomes. ATP support increases the level of effort the company devotes to the R&D phase of technology development. When the R&D process is a search or sampling process, as it is for the technologies we evaluated, the more effort spent searching, the more likely the entrepreneur is to find a successful solution to the problem—if there is one.[5]

Technical Phase

The R&D phase is characterized by large technical uncertainties regarding the outcome of the effort. Since the projects' technical development phase was not completed at the time of the study, our modeling of the R&D effort for these tissue-engineering projects also evaluates ATP's expected impact on the probability of technical success as well as on the timing of any success.

Commercialization Phase

During the commercialization phase, a firm invests in product development research, for example, in conducting clinical trials, establishing a production facility, or gaining regulatory acceptance. This phase is characterized by marketing uncertainties regarding the venture, and only occurs if the R&D effort is at least partially successful. The commercializing firm may or may not be the innovator or the innovator's partner or collaborator.

Diffusion Model

The diffusion of a successful technology and its gradual displacement of the defender technology characterize the technology production phase. The Bass diffusion model[6] captures the process of diffusion. To be accepted, the new technology must offer a lower-cost or better way of doing something.

Interviews with experts in the application of each technology provided information used to project the rate and ultimate market penetration of each tissue-engineering project. Using the resulting data in the Bass model gave the quantity of disease and illness treatment for the seven technologies over time for a given patient cohort.

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[5] See Hans P. Binswanger, "The Microeconomics of Induced Technical Change," in *Induced Innovation*, Hans P. Binswanger and Vernon Ruttan, editors, Baltimore, MD: Johns Hopkins University Press, 1978.

[6] See a description of the model in Frank M. Bass, "A New Product Growth Model for Consumer Durables," *Management Science*, 15(5):215-227.

Estimating Economic Returns

The economic benefits from the public and private investments in medical technologies are measured in terms of net present value (NPV), i.e., dollars adjusted for the time value of money. Benefits and costs that occur in future periods are "discounted" to make them comparable with those occurring in the present. The "discount rate"—used to adjust dollar amounts to an equivalent time basis—reflects the "opportunity cost" for funds available for either investment or consumption. A project with a NPV greater than zero, by definition, has economic values greater than prevailing alternative economic opportunities and, therefore, is worth doing.

If the NPV calculation takes into account the stream of revenues and costs to the investor alone, the NPV measures the private return on investment. Our estimation of private returns to the investor/innovator companies takes into account revenue resulting from sales of the new medical technology products, less all estimated development and production costs associated with bringing the new products to market.

If an investment imposes costs on, or conveys benefits to, others than the investor, and these costs and benefits are accounted for in the NPV calculation, the resulting NPV measures the social return on the investment. The social return includes not only the return to the private investor, but all effects both positive and negative that extend to others in society. The presence of large spillovers from R&D investments—particularly from investments in enabling technologies such as those promised by the ATP—significantly increase social benefits, and provide a major rationale for public funding of R&D. New medical technologies that cost no more, or even less than the best alternative treatments, and provide increased benefits to patients, generate spillovers in the form of consumer surplus or market spillovers.[7]

The social return on public investment is the incremental net return to society from the technology that is attributable to the public investment. It is the difference in societal returns with, versus without, the ATP funding.[8]

There are three ways ATP funding may increase social returns: (1) It can accelerate R&D, thereby leading to earlier introduction of the new technology. Receiving the benefits earlier or over more years will increase NPV. (2) It can increase the intensity of R&D, thereby increasing the probability of R&D success. (3) It can broaden the scope of R&D to include a wider range of potential applications and increased NPV.

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[7] For a description of market spillovers, knowledge spillovers, and network spillovers, see Adam B. Jaffe, *Economic Impact Analysis of Research Spillovers: Implications for the Advanced Technology Program*, NIST GCR 97-708, December 1996.

[8] Even if a new technology funded by the ATP results in large societal net benefits, this does not mean that the program has been successful unless a significant part of the net return is attributable to the ATP.

VALUING HEALTH BENEFITS

When a medical innovation results in an improvement in patient well-being, tracing a person's quality of life with and without the technology is required to value these benefits. The health state of any individual at any time is made up of his/her physical, psychological, and social functioning levels. Central to the study's evaluation of benefits from improvements in a patient's well-being are two concepts: Quality-Adjusted Life-Year (QALY) and value of life.

QALY is an approach to quantifying health benefits to the individual in terms of the quantity and quality of life.[9] A year of life in full health is given a QALY value of 1.0; death is given a QALY value of 0.0; and a year of life at less than full health is given a QALY value between 0.0 and 1.0. QALY values for selected health states are reported in health assessment literature. For example, living with mild angina has been assigned a QALY value of 0.90, and severe angina, a QALY of 0.50.[10]

QALY values assigned to different health states are derived from averages of survey results for relevant populations. Technology changes the availability of therapies and alters likely health outcomes. QALY values allow the analyst to quantify health improvements by accounting for changes in quantity and quality of life in a single measure.

We model the progression of chronic diseases treated by the tissue engineering projects as a Markow process where patients transition from one health state to the next over time. Health states are modeled throughout the remainder of patient statistical lives. Acute illness and injury are modeled as a single-period case of the chronic disease model.

QALYs are valued by scaling estimates of the value of a life-year in perfect health, obtained from economic studies of willingness to pay for such an outcome. "Value of life" means the value of a statistical life as indicated by a collective willingness to pay to avoid fatality risks.[11] We derived the value of a life year in perfect health from the value of a statistical life. this value is applied to the QALY changes associated with ATP support of each tissue engineering technology.[12]

The return on investment is expressed both in terms of NPV and as a percentage rate of return. Because of the uncertainty in project outcomes, substantial sensitivity analysisis employed.

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[9] George W. Torrance and David Feeny, "Utilities and Quality-Adjusted Life Years," *International Journal of Technology Assessment in Health Care*, 5:559-575.

[10] *Ibid*.

[11] See Josephine A. Mauskopf and Michael T. French, "Estimating the Value of Avoiding Morbidity and Mortality from Foodborne Illnesses," Risk *Analysis* 11(4):619-631; and Michael J. Moore and W. Kip Viscusi, "The Quantity-Adjusted Value of Life," *Economic Inquiry* 26(3):369-388.

[12] For additional description of the use of QALY values and value of life data, see A.J. Wang, "Key Concepts in Evaluating Outcomes of ATP Funding of Medical Technologies," Special Issue Editor: Rosalie Ruegg, *Journal of Technology Transfer*, 23(2):61-65.

FINDINGS

The general findings for the seven tissue engineering projects are as follows:

- The projects all have expected social returns much larger than their private returns, primarily due to projected positive spillovers to patients treated with the new technologies.
- ATP played a significant role in increasing the expected returns on these projects to the developers and to society at large by accelerating the R&D phase of the projects and improving the probability of technical success.
- Significant shares of the expected total social returns from the projects are attributable to the ATP.
- The expected return on ATP funding of the projects demonstrates a wide range of values, from about 20 percent to over 100 percent per annum over the projected time horizon.
- Projects that provide a relatively higher expected social return on investment have the following characteristics:
  - They apply to a large number of patients.
  - They have significantly better health outcomes than the defender technology.
  - They are cost-effective when compared to the defender technology.
  - They have a greater expected probability of technical success.

More specifically, Table 2 shows both the expected social return on investment and the expected social return on public investment (i.e., that part attributed

TABLE 2 Social Return on Investment and Social Return on Public Investment: ATP Projects in Tissue Engineering for a Single Preliminary Application

	Expected Social Return on Investment		Expected Social Return on Public Investment	
ATP Project	NPV (1996$ millions)	IRR (%)	NPV (1996$ millions)	IRR (%)
Stem Cell Expansion	134	20	47	21
Biopolymers for Tissue Repair[a]	98	51	98	51
Living Implantable Microreactors	74,518	149	17,750	148
Proliferated Human Islets	2,252	36	1,297	34
Biomaterials for Clinical Prosthesis	32,855	118	15,058	128
Gene Therapy Applications	2,411	106	945	111
Universal Donor Organs	2,838	91	783	92
Composite	109,229	115	34,258	116

[a] For Biopolymers, the two sets of figures are identical because all of the social return can be attributed to ATP investment.

to ATP funding) for each of the projects examined. The last row of the tablet shows the results for all of the projects taken together, i.e., the composite return.[13] The projects are projected to generate approximately $34 billion (NPV) in social return on public investment over a 20-year study period (encompassing all phases from R&D through commercial use). ATP funding is estimated to induce about 31 percent of the total social returns from all seven projects over the study period. For the individual projects, the effect of ATP on social returns ranges from about 25 to 100 percent of the social returns.

Social returns to these projects vary with such factors as the number of patients treated, the value of the health benefits of the new technology, their impact on health-care costs, and the probability of technical success. "Stem Cell Expansion" and "Biopolymers for Tissue Repair" include health-care cost savings but no health well-being benefits due to the unavailability of QALY data for the associated health effects. The projects "Living Implantable Microreactors" and "Proliferated Human Islets" provide similar health benefits but differ with respect to their impact on health-care costs and their probability of technical success.

LIMITATIONS

We recognize the conjectural nature of our findings and limitations of our methodology. Modeling the entire process from R&D to health outcomes obviously entails the use of a large amount of estimated data and the use of assumptions when data are lacking. Much of the data were, as it must be, gathered from the firms supported by the ATP and from other key participants in the medical care sector. Only time will tell if the expectations of these firms are fully realized.

Despite the limitations, this approach provides a useful framework for evaluating ATP contributions to social welfare from funding medical technology. The framework requires that the analyst explicitly examine the entire process from R&D to patients with injuries and illnesses who would receive treatments based on the new technologies if they are successfully commercialized and diffused. The approach is based on widely accepted economic reasoning to develop estimates of the impacts of ATP funding on project timing and success. It incorporates spillovers, and employs counterfactuals for comparison of the with- and without-ATP-funding scenarios. It uses sensitivity analysis to reflect uncertainties. And, it employs traditional valuation metrics to value the social-welfare implications of the impacts.

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[13] We calculate the composite measure of NPV for the seven case-study projects by summing the total expected benefits and costs (negative values) for each year for all the projects and discounting the resulting amounts over a time period that covered the life of all projects.

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Enhanced R&D Efficiency in an ATP-funded Joint Venture

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ABSTRACT

This study focuses on the impact of an Advanced Technology Program (ATP) joint-venture project on costs and timing of developing a suite of "leap-frog" technologies for the U.S. printed wiring board industry. To a lesser extent, it also looks at early-stage benefits of adopting the new technologies. It examines developments from mid-1991 through mid-1996 when the project was underway, and at its end.

A printed wiring board (PWB) provides electrical interconnections and a surface for mounting electrical components. PWBs are the backbone of electronic devices common in most industry sectors. Most of the hundreds of small U.S. companies producing PWBs lack the capability to mount advanced research efforts, and users of the boards pointed to a growing need to switch to overseas suppliers unless U.S. producers could achieve dramatic improvements by the mid-1990s. With encouragement and administrative leadership from the National Center of Manufacturing Science (NCMS), a group of seven research-capable companies within the industry plus Sandia National Laboratories proposed a far-reaching research program to the ATP to increase competitiveness of U.S. producers.

The study finds that the participants' collaborative activities had a dramatic effect on R&D efficiency, resulting in a cost savings of at least $35.5 million. The increased research efficiency led in turn to reduced cycle times for both new project development and new process development. Collectively, the result has meant productivity improvements for member companies, diffusion of the technology to other producers, and improved competitive positions for participating companies in the world market.

DECLINE IN U.S. SHARE OF GLOBAL PWB MARKET

The United States dominated the world PWB market in the early 1980s, as shown by Table 1, but lost that dominance by the late 1980s. While no single event explains the decline in U.S. market share, according to one company spokesperson a very important factor has been "budget cut backs for R&D by original equipment manufacturers (OEMs) because owners demanded higher short-term profits," which led to deterioration of the industry's technology base.

In 1991, the Council on Competitiveness issued a report on American technological leadership.[1] Motivated by evidence that technology has been the driving force for economic growth throughout American history, the report documented that as a result of intense international competition, America's technological leadership had eroded. In the report, U.S. technologies were characterized in one of four ways: *Strong:* meaning that U.S. industry is in a leading world position and is not in danger of losing that lead over the next five years. *Competitive:* meaning that U.S. industry is leading, but this position is not likely to be sustained over the next five years. *Weak:* meaning that U.S. industry is behind or likely to fall behind over the next five years. *Losing Badly or Lost:* meaning that U.S. industry is no longer a factor or is unlikely to have a presence in the world market over the next five years. The 1991 Council on Competitiveness report characterized the U.S. PWB industry as "Losing Badly or Lost."

ATP AWARD TO THE PWB JOINT VENTURE

In 1990-91, the Advanced Technology Program conducted its first competition. A joint venture proposal, by the National Center for Manufacturing Science (NCMS), proposes to research and develop a suite of advanced PWB technologies that would enable U.S. wire board suppliers to meet the needs of customers, making it unnecessary for them to rely on foreign suppliers. The ATP selection board found that the proposed project met technical and economic criteria, and it announced the PWB joint venture in the first group of 11 ATP award winners.

The project ran through April 1996. ATP contributions amounted to $12.87 million over the five-year (statutory limit) funding period. Industry matching contributions amounted to $13.78 million. During the project, the U.S. Department of Energy added an additional $5.2 million, bringing total project research costs to $31.85 million.

Early Evaluation

As part of its evaluation effort, the ATP wanted to gain an early understanding of the workings of the joint ventures it funded. It commissioned two studies

[1] Council on Competitiveness, *Gaining New Ground: Technology Priorities for America's Future*, Washington, D.C.: 1991.

TABLE 1 World Market Share for Printed Wiring Boards

Year	U.S. (%)	Japan (%)	Others (%)
1980	41	20	39
1981	40	22	38
1982	39	23	38
1983	40	21	39
1984	42	24	34
1985	36	25	39
1986	34	32	34
1987	29	30	41
1988	28	27	45
1989	28	31	41
1990	26	35	39
1991	27	34	39
1992	29	31	40
1993	26	28	46
1994	26	26	48

of the Printed Wiring Board Joint Venture, the first in 1993, two years after it began; and a second in 1996, soon after it ended. This paper reports the results of those studies.[2]

ROLES AND RELATIONSHIPS AMONG MEMBERS OF THE JOINT VENTURE

Participants in the PWB Joint Venture, in addition to NCMS, plus changes over the course of the project are summarized in Table 2. Although Digital Equipment (DEC) was one of the companies involved in the original NCMS proposal to ATP, it participated in the project for only 18 months. Its decision to withdraw was, according to NCMS, due strictly to financial conditions at the corporation at that time. DEC's financial condition did not improve, ultimately leading to the closing and sale of its PWB facilities.

After DEC dropped out, three other companies joined the joint venture to assume its research responsibilities. These were AlliedSignal in 1993, Hughes Electronics in 1994, and IBM also in 1994. In addition, Sandia National Laboratories became involved in the joint venture during 1992, as anticipated in the proposal for funding. Sandia subsequently obtained an additional $5.2 million from the Department of Energy and applied it towards the research effort of the joint venture.

[2] A. N. Link, *Advanced Technology Program: Economic Study of the Printed Wiring Board Joint Venture After Two Years*, report prepared for the Advanced Technology Program, April 1993; and A. N. Link, *Advanced Technology Program Case Study: Early Stage Impacts of the Printed Wiring Board Joint Venture, Assessed at Project End*, NIST GCR 97-722, November 1997.

TABLE 2 Membership Changes in the PWB Research Joint Venture

Original Members, April 1991	1992	1993	1994	April 1996
AT&T	AT&T	AT&T	AT&T	AT&T
Digital Equipment	—	—	—	—
Hamilton Standard	Hamilton Standard	Hamilton Standard	Hamilton Standard	Hamilton Standard
Texas Instruments	Texas Instruments	Texas Instruments	Texas Instruments	Texas Instruments
—	—	AlliedSignal	AlliedSignal	AlliedSignal
—	Sandia	Sandia	Sandia	Sandia
—	—	—	Hughes Electronics	Hughes Electronics
—	—	—	IBM	IBM

A Horizontal Collaboration

The PWB research joint venture can be described in economic terminology as a horizontal collaborative research arrangement. Economic theory and empirical studies suggest that research efficiencies will be realized when horizontally related companies form a joint venture, due to the reduction of duplicative research and the sharing of research results.[3] This conclusion is supported in this case study's quantitative estimates of cost savings.

Less Competition, More Cooperation

Characteristics of the joint venture member companies are summarized in Table 3. An important point to note is that AT&T, Hughes, IBM, and Texas Instruments, although in the same broadly defined industry, are not head-to-head competitors. These companies were four of the leading domestic captive producers of PWBs when the project began; they were also members of NCMS, the joint venture administrator. However, AT&T and IBM were not direct competitors in PWBs because their PWBs were produced for internal use in different applications. AT&T produced PWBs primarily for telecommunications applications while IBM's application areas ranged from laptop to mainframe computers. Similarly, Hughes and Texas Instruments produced for different niche markets (although they did compete with each other in some Department of Defense areas). Hamilton Standard, no longer a producer, purchased boards to use in its

[3] A. N. Link and Laura L. Bauer, *Cooperative Research in U.S. Manufacturing: Assessing Policy Initiatives and Corporate Strategies*, Lexington, MA: D. C. Heath, 1989.

TABLE 3 Characteristics of Members of the Joint Venture

Member Company	Type of Producer	Primary Market Niche
AT&T	captive	telecommunications
Hamilton Standard	n.p.	aerospace
Texas Instruments	captive	computers
AlliedSignal	captive	defense
Sandia	n.p.	n.p.
Hughes Electronics	captive	computers
IBM	captive	computers

Note: PWB producers are divided into two general groups: manufacturers that produce PWBs for their own end-product use and manufacturers that produce boards for sale to others. Those in the first group are referred to as original equipment manufacturers (OEMs) or captives, and those in the second group are referred to as independents or merchants.

production of engines and flight control electronics. AT&T and Texas Instruments were not involved in these latter two product areas. In contrast to all of the other companies, AlliedSignal was a major supplier of materials (e.g., glass cloth, laminates, resins, copper foil) to the PWB industry. In addition, it was a small-scale captive producer of multilayered PWBs. The absence of an intensely competitive situation among the joint-venture participants is noteworthy because it is likely more conducive to their sharing results.

Organizational Structure of the Joint Venture

NCMS provided the program management, coordination, facilitation, and interface with ATP for the PWB project. NCMS coordinated and interfaced the administrative functions of accounting, contracts, and legal functions related to intellectual property agreements. A Steering Committee, with a senior technical representative from each participating organization, directed and controlled four research teams to ensure that each met the project's technical goals.

Maintaining Accountability

The joint venture was organized to "mimic a company with a chain of command," according to one member of the Steering Committee. According to this member:

> "If it was not organized this way then no one would be accountable. Most of the people had this project built into their performance review. If they failed on the project then they failed at work. The structure also allowed ease of reporting. The information flowed up to the team leader as the focal point for information distribution. The team leader would then report to the Steering Committee made up of senior managers who were paying the bills."

FOUR FOCUS AREAS

Prior to proposing to ATP's 1990 General Competition, the members of the research joint venture conducted a systems analysis of the PWB manufacturing process and concluded that fundamental generic technology development was needed in four components of the process to develop the capabilities needed for global competitiveness. Accordingly, the joint venture's research activities addressed four areas:

- Materials;
- Surface Finishes;
- Imaging; and
- Product (research; not product development).

Each component consisted of a combination of research areas which (1) provided significant improvements to existing processes, and (2) explored new technology to develop breakthrough advances in process capabilities.

A multi-company team of researchers was assigned to each of the four research teams. They were involved in 62 separate tasks, and had specific research goals as noted in the following team descriptions:

***Materials Team*:** The majority of PWBs used today is made of epoxy glass combinations. The goal of the Materials Team was to develop a more consistent epoxy glass material with improved properties. The team was also to develop non-reinforced materials that exceeded the performance of epoxy materials at lower costs. Better performance included improved mechanical, thermal, and electronic properties (e.g., higher frequency) to meet improved electrical performance standards.

***Surface Finishes Team*:** Soldering defects that occur during assembly require repair. The goal of the Surface Finishes Team was to develop test methods to use during fabrication to determine the effectiveness of various materials used during the soldering process and to develop alternative surface finishes.

***Imaging Team*:** The goal of the Imaging Team was to investigate and extend the limits of the imaging process to improve conductor yield, resolution, and dimensional uniformity.

***Product Team*:** Originally, this team was known as the chemical processing team. Its goal was to investigate the feasibility of additive copper plating and adhesion of copper to polymer layers. When input from the industry revealed this was not the best research path to take, its focus changed—as did its name. The revised goal of the Product Team was to develop high density interconnect structures.

Given the generic research agenda at the beginning of the project, the organizational structure seemed conceptually appropriate for the successful completion of all research activities. At the close of the project, this continued to be the opinion of the members. As a member of the Steering Committee noted:

> "There is better synergy when a management team directs the research rather than one company taking the lead. Members of the Steering Committee vote on

membership changes, capital expenditures, licensing issues, patent disclosures and the like. As a result of this type of involvement, there are high-level champions in all member companies rather than in only one."

TECHNICAL ACCOMPLISHMENTS

The PWB Research Joint Venture Project accomplished the originally proposed goals, and the project exceeded the original expectations of the members. The joint venture entailed 62 distinct research tasks carried out by the project's four research teams. Technical accomplishments included the following, among many others:

(1) The Materials Team developed the technology for making single-ply laminates and a new, dimensionally stable thin film material superior to any other used by the industry.
(2) The Surface Finishes Team improved test methods that determine the effectiveness of various materials during the soldering process.
(3) The Imaging Team developed and demonstrated the process required to obtain a yield of greater than 98 percent for 3 mil line and space features.
(4) The Product Team (also a research team) developed a revolutionary new interconnect structure and demonstrated its feasibility in production.

CONCEPTUAL APPROACH TO THE ANALYSIS OF RESEARCH COST SAVINGS, EARLY PRODUCTIVITY GAINS, AND OTHER EFFECTS

In a survey conducted during this study, participants in the joint venture were asked to quantify a number of related metrics comparing the end-of-project technological state to the technological state that would have existed at this time in the absence of ATP's financial support of the venture. Additional questions were also posed to team leaders in an effort to obtain insights about broader effects of the joint venture on the industry as a whole.

In the earlier (1993) study of the joint venture, it was estimated that only 6.5 of the 29 then ongoing tasks in the venture would have been started without the ATP award. The number of research tasks increased to 62 as the companies collaborated to identify and solve new problems. At project's end, team leaders estimated that about half of the 62 projects would not have been started in the absence of ATP funding.

A counter-factual survey also examined the subset of tasks participants thought would have been started even in the absence of ATP support. The survey focused on only one dimension of economic impact, namely cost savings attributable to formation of the joint venture, in terms of only those projects that the member companies would have pursued individually in the absence of the ATP supported joint venture.

The limited focus had both positive and negative aspects. On the positive side, it ensured participation in the economic analysis by all members of the joint venture. It also ensured that estimates of quantified impacts would represent a lower bound estimate of the project's actual economic value. On the negative side, while a number of technical project-generated accomplishments have the potential to generate large economic benefits to the PWB industry and consumers, the study provided no aggregate estimate of their long-term potential value. Looking at developments several years downstream from the end of the project should shed more light on the diffusion of the technologies developed in the project and their benefits.

MEASURING IMPACT

The methodology used to collect information for this study was defined, in large part, by the members of the joint venture. In particular, members requested that the information collected first be screened by NCMS to ensure anonymity and confidentiality, and only be provided for the study in aggregate form through NCMS. Under this condition, all members of the PWB research joint venture were willing to participate in the study by completing a limited survey instrument and returning it directly to NCMS.

The survey instrument considered these related categories of direct impact:

- Scale, Scope, and Coordination Efficiencies: Estimated Work Years Saved by Carrying Out the Research as a Joint Venture;
- Testing Materials and Machine Time Savings;
- Other Research Cost Savings;
- Cycle-Time Efficiencies: Shortened Time to Put into Practice New Procedures and Processes; and
- Productivity Increases in Production.

The survey also considered two broad categories of indirect impact:

- Early Technology Transfer to Firms Outside the Joint Venture;
- International Competitiveness Issues; and
- a third category, Other Company Impacts.

Focused survey findings were supplemented with selected open-ended comments offered by respondents; personal discussions with team leaders and company representatives during the April 1996, Steering Committee meeting; and by follow-up telephone and e-mail discussions with available members.

ATP Funds Critical to Cooperation

All members concurred that the joint venture would not have formed in the absence of ATP funds to leverage the overall research program. Members were asked which relevant research tasks their company would have started in the absence of the ATP-funded joint venture. Aggregate responses suggested that only one-half of the tasks would have begun in the absence of ATP funding. The other one-half would not have been started because of the cost and related risk. Tasks that would not have been started without ATP funding included: development of alternative surface finishes, projection imaging evaluations, revolutionary test vehicle designs, plasma process monitoring equipment, PTH modeling software, and approximately 25 others.

Of those tasks that would have been started without ATP funding, qualitative responses indicated that the majority would have been delayed by one year or more for financial reasons.

Direct Impact on Member Companies

Regarding the five categories of direct impacts:

1. Scale, Scope, and Coordination Efficiencies: Estimated Work Years Saved by Carrying Out the Research as a Joint Venture

Two years into the project, the members estimated a total of 79 work years had been saved from avoiding redundant research, valued at more than $10 million.[4] At the end of the project, the members estimated a total of 156 work years had been saved. The total value of these work years saved was estimated at $24.7 million. The estimated $24.7 million in savings was based on an estimate of additional labor costs member companies would have incurred if the designated half of the research tasks were in fact actually carried out individually and without collaboration.[5] A member of the Steering Committee provided an example of work years saved by avoiding redundant research:

> "The universal test vehicle developed by the imaging team was the foundation for the co-development and sharing of research results. Two examples of this relate to the evaluation of etchers and the evaluation of photoresists. Regarding etchers, one of the member companies did the initial evaluation, Sandia did the validation, and other member companies implemented the findings. Similarly, individual companies evaluated selected photoresists and then shared their results with the others. All members benefited from the joint development and sharing by avoiding redundant research time and expenses."

[4] Link, *Advanced Technology Program: Economic Study of the Printed Wiring Board Joint Venture After Two Years, op. cit.*

[5] A. N. Link, David J. Teece, and William F. Finan, "Estimating the Benefits from Collaboration: The Case of SEMATECH," *Review of Industrial Organization,* 11(5):737-751.

2. Testing Materials and Machine Time Savings

Two years into the project, the members estimated cost savings to be over $2 million from avoiding redundancies in research testing materials and research machine time. At the end of the project, the members estimated the total value of savings in those areas to be over $3.3 million. Relating to research testing materials savings, a member of the Steering Committee noted:

> "Before the consortium, there was no central catalogue of all base materials used to produce printed wiring boards. Now, the Materials Component of the PWB research joint venture has produced a complete database of PWB materials that includes data on composition, qualifications, properties, and processing information for the domestic rigid and microwave materials. The information in this catalogue has saved research testing materials and will make it easier for designers and fabricators to select materials without having to search through supplier literature."

This member went on to note:

> "Considerable problems were encountered in creating the database because:
>
> (1) materials suppliers do not provide standardized property test data;
>
> (2) all of the data needed to process the material were not readily available; and
>
> (3) some of the test data appeared to be exaggerated. The database is presently available within the consortium and there are plans to make the database available to the entire industry over the Internet."

3. Other Research Cost Savings

In the 1993 study, members were asked a catchall question relating to all other research cost savings associated with the research areas that would have been started in the absence of ATP funds, excluding labor and research testing material and machine time. In 1993, these other cost savings totaled $1.5 million. In the 1996 survey, the same catchall question was asked, and members' responses gave cost savings of over $7.5 million.

Therefore, quantifiable research cost savings attributable to ATP funds and the formation of the joint venture were $35.5 million at the end of the project—$24.7 million in work years saved, $3.3 million in testing material and machine time saved, and $7.5 million in other research cost savings. In other words, members of the joint venture reported that they would have spent collectively an additional $35.5 million in research costs to complete the identified subset of research tasks that they would have conducted in the absence of the ATP-funded joint venture.

4. Cycle-Time Efficiencies: Shortened Time to Put into Practice New Procedures and Processes

Two years into the project, members estimated that about 30 percent of the tasks enjoyed shortened time to put new procedures and processes into research practice, and the average time saved per research task was nearly 13 months. At the end of the project, members estimated that shortened time to practice was realized in about 80 percent of the research tasks that would have been started in the absence of ATP funds, and the average time saved per task was 11 months. Members did not quantify the research cost savings or potential revenue gains associated with shortened time to practice.

As an example, a member of the Steering Committee noted:

> "The use of the AT&T image analysis tool and the improvements made in the tool during the contract has made a significant reduction in the evaluation time needed for photoresist process capability studies. This reduction has occurred due to the improved test methodology and the significant improvements in the speed and accuracy now available in making photoresist analysis."

5. Productivity Increases in Production

Two years into the project, members of the Steering Committee estimated that participants had realized productivity gains in production which could be attributed to research developments in about 20 percent of the 29 research areas. The then-to-date production cost savings totaled about $1 million.

At the end of the project, the members estimated they were realizing productivity gains in production which could be traced to research developments in about 40 percent of the 62 research areas. The teams estimated the value of these productivity gains in production, to date, to be just over $5 million. And, given that the PWB research joint venture's research had just completed, future productivity gains will, in the opinion of some team leaders, increase exponentially.

One example of productivity improvements in production relates to switching from two sheets of thin B-stage laminate to one sheet of thicker B-stage laminate. One committee member noted:

> "For a business like ours, the cost saving potential was enormous. The problem was that reducing the ply count in a board carried risk: drill wander, reliability, thickness control, dimensional stability, and supply. The consortium provided the resources to attack and solve each of these problems. The result was that we were able to quickly convert all production to thicker B-stage, saving at least $3 million per year. Without the consortium this conversion might not have occurred at all."

A second committee member's example relates to dimensional stability:

> "The inability to accurately predict inner layer shrinkage leads to a serious compromise with interconnection density and often leads to costly scrap. At the be-

> ginning of this program, our facility was in the 8 to 10 mil range and misregistration scrap costs were in the range of $1.5 million per year. This problem was an area of special concern to the consortium members. As a result of this project, data exist that lead to an understanding of the problem, and a predictive model has been developed that is now being used to compensate for the art work associated with the circuit image on the boards. Our current capability is 5 to 6 mils and scrap is below $100,000 per year. The work of the consortium made these improvements possible."

A third member of the Steering Committee reported:

> "Our company has reduced solderability defects by 50 percent due to the efforts of the surface finishes team on the PWB interconnect program. The defect levels decreased from 4 to 2 defects per 1,000 solder joints due to reduced variation in tin alloy and contamination at the solder reflow process (note that there are more than 1,000 solder joints per PWB.)"

And a fourth member commented:

> "The data collected from the NIST ATP program for improved registration and productivity gains were presented to the Defense Electronic Supply Center to convince them to allow single ply prepegs in construction of military PWBs. My company will obtain an ongoing benefit from this due to a 30 percent reduction in materials cost and improved registration of the PWBs which will improve yield."

Indirect Impact on Member Companies and the PWB Industry

The study identified two categories of indirect impact already extending beyond the member companies to the entire industry:

- advanced scientific knowledge important to making PWBs; and
- improvements in international competitiveness.

Descriptive information was collected to illustrate the breadth of the impacts, but no effort was made to estimate aggregate dollar value or to define them as tasks that would or would not have been begun in the absence of ATP funding. This approach was based on advice of the Steering Committee, which felt that dollar valuations at this time would be extremely speculative.

1. Technology Transfer to Firms Outside the Joint Venture

Two years into the project, the members reported that they had presented 12 research papers to various industry groups, attended 40 professional conferences fundamental to the research of the joint venture, and shared information from the research tasks with about 30 percent of the industry supplying parts and materials to the PWB industry. Additionally, members of the Imaging Team had interacted personally with suppliers of resist materials to the industry.

At project's end, participants had presented 214 papers related to the research findings from the PWB project, 96 at professional conferences, and had additional papers scheduled for presentation.

Members of the joint venture offered the opinion that such transfers of scientific information benefited the PWB industry as a whole by informing other producers of new production processes. They also benefited the university research community as evidenced by the fact that these papers are being cited in academic manuscripts.

Material Team members attended 10 conferences where they interacted with a significant portion of the supplying industry. Specifically, they estimated that they interfaced regarding the PWB project with 100 percent of the glass/resin/copper suppliers, 100 percent of the flex laminators and microwave laminators, 90 percent of the rigid laminators, and 50 percent of the weavers.

Members of the Steering Committee were asked to comment on the usefulness of these technology transfer efforts. While all thought they were important to the industry, one member commented:

> "One indication of the successfulness of the technology transfer efforts can be reflected in the fact that two of the PWB program papers presented at the IPC conferences were selected as best papers at these conferences. The IPC conferences are recognized worldwide as the premier PWB industry conferences. I think this shows that the industry appreciated the depth of the technology effort. Another indication of the usefulness of the technology transfer process is the fact that new PWB manufacturers are exhibiting interest in joining two proposed follow-on programs to continue certain areas of the current research."

Another member noted that his company relied on an independent PWB shop for dense boards. A measure of the success of the technology transfer is that this supplier, which did not participate in the project, had also increased its yield of these boards.

2. International Competitiveness Issues

The health of the domestic PWB industry is fundamental to these companies' ability to be more competitive in the world market. At a recent meeting, NCMS gave its collaborative project excellence award to the ATP-sponsored PWB project. At that meeting the NCMS president credited the project with saving the U.S. PWB industry and its 200,000 jobs.

The members of the PWB Research Joint Venture perceived that, as a result of their involvement in the joint venture, their companies have become more competitive in certain segments of the world market such as computing, the fastest growing market for PWBs. Although any one member company is involved in only one or two market segments, all members indicated that their companies' market share either stabilized or increased *as a result of* being involved in the PWB project.

Likewise, members perceived that the domestic PWB industry as a whole has increased its competitive position in selected world markets as a result of the accomplishments of the joint venture. With regard to the venture's impact on the industry share in the different segments of the world market, most respondents indicate that the project increased the industry's share in every market segment, with the strongest positive responses in the computer and military segments. No member believed the joint venture members had increased their share at the expense of nonmembers. This can be attributed to the fact that the results of the PWB project have been widely disseminated.

3. Other Company Impacts

Members of the Steering Committee were asked to complete the following statement: "My company has benefited from its involvement in the PWB joint venture in such nontechnical ways as . . . "

Representative responses were:

- — "We have learned to work and be much more open with other industry members."
- — "We have learned where other companies stand on technology."
- — "We have learned we in the industry all have the same problems and can work together to solve them."
- — "We have learned how to work with the Federal Labs, something we have never done before."
- — "We have an increased awareness of industry trends, needs, and approaches."
- — "We have learned that our company's intellectual property is not as proprietary as we initially believed—rarely can it be directly applied by our industry colleagues."
- — "We have gained prestige from being associated with the program."
- — "The joint NCMS/NIST/ATP research program has a national recognition. Suppliers that would not normally participate in collaborative projects will when a team like this is formed to become a joint customer."

Finally, the members considered the goals of the ATP as stated in its enabling legislation. Albeit qualitative information, the members of the Steering Committee generally agreed that the ATP had indeed fulfilled its stated goals in the case of the PWB Research Joint Venture.

In 1994, the Council on Competitiveness updated its report and upgraded its assessment of the domestic industry to "Weak" due in large part to renewed R&D efforts by the industry.[6] More recently, industry spokespersons have heralded signs of an industry turnaround.

SUMMARY AND CONCLUSION

ATP's funding of the PWB Research Joint Venture Project has had a number of direct and indirect economic impacts. Of the direct impacts, the largest at the time the study was conducted in 1996 was the increase in R&D efficiency. The project achieved at least a 53 percent reduction in overall research costs. The increase in research efficiency in turn led to reduced cycle times for both new project development and new process development. Collectively, the result has meant productivity improvements for member companies and improved competitive positions in the world market. As a result of knowledge dissemination activities by members of the joint venture, capabilities across the entire industry are expanding. These technology advancements are thus improving the competitive outlook and world market share of the U.S. PWB industry.

The survey findings associated with the above direct and indirect economic benefits are summarized in Table 4. In that table, the categories of direct economic impacts to joint-venture participants are separated into those for which dollar values were obtained and those for which dollar values were not obtained, i.e., into "quantified and non-quantified economic impacts."

The results described in this paper and summarized in Table 4 should be interpreted as only partial and preliminary estimates of project impacts. First, although ATP funding of the joint venture led directly to research cost savings and early production cost savings and quality improvements, the bulk of the production cost savings and performance gains would not be expected to occur until more time has passed after the project's end. Implementation of the new process technologies by joint-venture participants and diffusion of the technologies to other companies in the industry take time. As such, the economic impacts to which values are attached in Table 4 provide a conservative lower-bound estimate of the long-run economic benefits associated with ATP's funding of the joint venture research. The study did not include consideration of market-determined economic benefits deriving from the joint venture research.

[6] Council on Competitiveness, *Critical Technologies Update 1994,* Washington, D.C.: 1994.

TABLE 4 Summary of Survey Findings on Partial Early-Stage Economic Impacts

Categories of Partial Early-Stage Economic Impacts	2 Yrs After Project Start	At End of Project
Direct Impacts on Member Companies		
Quantified Economic Impacts*		
Research Cost Savings		
Work years saved	$10.0 mil.	$24.7 mil.
Testing materials and machine time saved	$2.0 mil.	$3.3 mil.
Other research cost savings	$1.5 mil.	$7.5 mil.
Production Cost Savings		
Productivity improvements	$1.0 mil.	$5.0 mil.
Non-Quantified Economic Impacts*		
Shortened Time to Practice		
Average time saved per research task	12.7 months	11.0 months
Indirect Impacts on Member Companies		
Competitive Position in World Markets	increased	increased
Spillover Impacts on PWB Industry		
Technology Transfer		
Research papers	12	214
Conferences attended	40	96
Competitive Position in World Markets	increased	increased

* Indicates these impacts are based only on half the research tasks the members thought they would eventually have done without the ATP, and not the new capabilities resulting from those tasks that they would not have done at all without the ATP.

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Estimating Future Benefits from ATP Funding of Digital Data Storage

David Austin and Molly Macauley
Resources for the Future

KEY POINTS

- This paper illustrates how the ATP has extended the state-of-the-art of evaluation for programs which support the development of new technologies. An important caveat to keep in mind is that the paper does not claim the estimated benefits are realized, or will be. It does provide a means to estimate the potential returns to R&D investments, in this case, if the new ATP-funded technologies are adopted.
- This study generates these estimates by drawing on previous economic modeling to develop and apply a novel new method for estimating consumer benefits from advanced technology under development or under consideration.
- The resulting cost index model is tested by estimating expected consumer welfare gains from two ATP-funded innovations in digital data storage (DDS)—both expected to offer dramatic price/performance improvements compared to existing tape drives if they are successfully commercialized.
- The analysis yields expected benefits to consumers from the optical tape technology in excess of $1 billion, and from the linear scanning technology, $2 billion, both taken over a five-year period, and conservatively estimated.
- Based on experimental use in assessing ATP projects, the method appears suitable for use by other federal and state government programs to develop performance measures for programs which support the development of advanced technology.

OVERVIEW

This papers develops and applies a new method for estimating consumer benefits from advanced technology. The new method takes into account changes in the quality of service provided by the new technology. We apply the method to evaluate two ATP-funded innovations in data storage technology.

- One innovation, undertaken by LOTS Technology, Inc., is an optical tape read/write technology representing a dramatic increase in data storage capacity.
- The second innovation, carried out by Imation Corporation, is to develop underlying technology for linear scanning of magnetic tape that, at a fraction of the cost, can match or exceed the performance and capacity of a helical-scan system, a competing technology led by offshore competitors.

Both technologies promise dramatic price/performance improvements compared to existing tape drives. Applying the new evaluation method, we estimate the expected benefits to consumers from the optical tape technology to exceed $1 billion, and from the linear scanning technology, $2 billion, both taken over a five-year period, and conservatively estimated. This study focuses on consumer benefits from early commercialization of the technologies, and ignores benefits accruing to the innovator, or to other manufacturers via knowledge spillovers, as well as benefits from second-generation products.

DEVELOPING A MODEL FOR ESTIMATING BENEFITS TO CONSUMERS

In any R&D program, a key challenge for public and private managers alike is to assess what the outcomes and longer run impacts will be. Government programs, such as the ATP, are particularly concerned about how consumers will benefit from the innovations being developed.

Traditionally, forecasts of how consumers will benefit from an innovation have been difficult, particularly when the innovation is a high-tech link in a chain that ends with a benefit to the consumer. The quality of service is not readily observable and is difficult to measure quantitatively.

Work by Stanford's Timothy Bresnahan[1] made it more feasible to estimate consumer benefits from quality of service improvements. He developed a cost-of-living index that, under certain general assumptions, makes it possible to compare observed price and performance for an innovated product against hypothetical, best-available price and performance had the technical advance not occurred. Bresnahan's method was aimed at retrospective evaluation; that is, for

[1] Timothy Bresnahan, "Measuring the Spillovers from Technical Advance: Mainframe Computers in Financial Services," *American Economic Review*, 76(4):742-755, 1986.

estimating consumer benefits from already existing innovations rather than for forecasting consumer benefits from innovations still under development.

A Prospective Approach

To meet the challenges facing R&D managers, we extend Bresnahan's method to make it suitable for prospective assessments of consumer benefits from proposed R&D projects and those that have not yet resulted in products on the market. Our approach allows for the gradual diffusion of the new technology, and we express the model's parameters as probability density functions to reflect uncertainties over future or estimated parameter values.

We also extend Bresnahan's method to have it reflect consumer preferences for specific product characteristics—speed, for instance—and to take into account the fact that those preferences may affect the product's success in a competitive marketplace. Differentiated product characteristics may provide benefits not fully reflected in product prices.

A Tool to Estimate Potential Benefits

The resulting method can be used for estimating the potential benefits of a technology under development or under consideration. Thus it has potential as a tool to guide the allocation of both private-sector and government R&D investments to projects with high potential for consumer benefits, as well as to evaluate potential consumer benefits per se. For federal government programs like the ATP, this methodology is suitable to meet the requirements of the Government Performance and Results Act for performance measures.

Illustration of an Expected Gain in Consumer Benefits Figure 1 illustrates the expected gain in consumer benefits from a technological innovation, such as an improvement in the ability to store large amounts of data. The left-hand panel of the figure shows the pre-innovation baseline, where only a *defender technology* is available, whose supply is represented by S_0^{DT}. The downward sloping line, *D*, represents demand for data storage. The right-hand panel of Figure 1 shows the ATP-sponsored innovation—a combination of cost reductions and quality improvements—that occurs in a subsequent time period. The innovation is represented as an outward shift in the supply curve to S_1^{ATP}. In the meantime, the defender technology may also have improved and shifted the baseline supply curve to S_1^{DT}. The shaded area represents the consumer welfare gain ("consumer surplus") at a point in time, due to the innovation. It is measured with respect to the hypothetical, future S_1^{DT} curve rather than the observed S_0^{DT}. As long as S_1^{ATP} lies to the right of S_1^{DT}, the innovation offers an expected improvement over the defender technology.

Cost Index Model Measuring the gain is straightforward if the demand curve can be estimated using econometric techniques. But this is difficult to do in

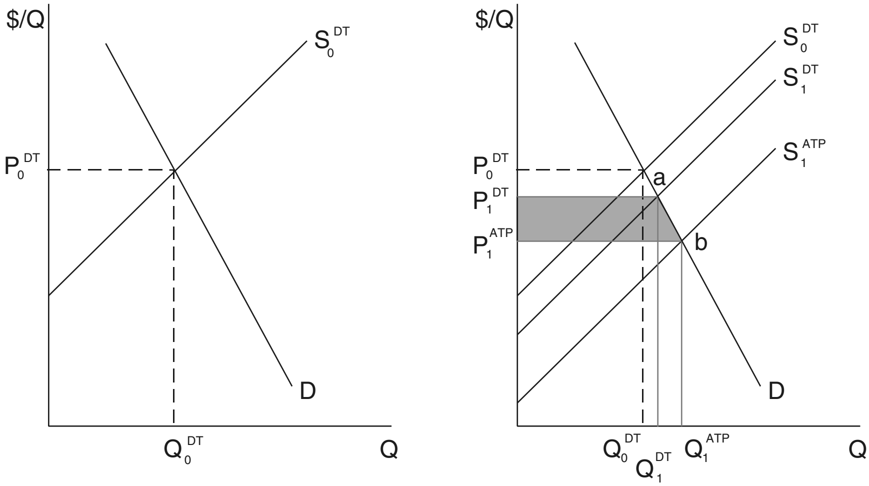

FIGURE 1 Derived demand for new technologies: Illustration of net surplus change

service sectors, where real output is not readily observed, yet where much of the demand for high technology is located. In this case, the Tornqvist cost-index approach pioneered by Bresnahan is attractive, because it does not require estimating a demand curve. To paraphrase Brasnahan, the method substitutes economic theory for (unobservable) data. With reference to Figure 1, the cost index will be greater than unity, meaning costs would be higher under the baseline scenario and consumers will be better off (gross of R&D costs) if the innovation occurs.

The index is an estimate of the change in the cost-of-living (in the sense of consuming digital data storage-using services) under the innovation scenario, relative to the baseline. To construct the index, we adjust nominal unit prices of off-the-shelf devices to reflect consumer preference for faster data transfer rates, larger capacities, and lower file access times.[2] We assume that these "shadow values" decline over time, reflecting consumers' declining marginal utilities. For example, an extra gigabyte of storage capacity is more valuable to a consumer who has only ten gigabytes storage than to a consumer with 100 gigabytes. The value of a given increase will decline over time as performance further improves.

[2] A discussion of quality-adjustment methods employed by the Bureau of Labor Statistics in the construction of the consumer price index (CPI) can be found in B. R. Moulton and K. E. Moses, "Addressing the Quality Change Issue in the Consumer Price Index," *Brookings Papers on Economic Activity I*, 1997, pp. 305-366. Unlike the CPI, which compares prices over time, the index used here compares prices in a single period: expected, future prices given the innovation versus hypothetical, future prices assuming no innovation.

In our applications of the technique, we almost always adjust the prices of the defender technologies. Their usually lower capacities and transfer rates, and longer file access time, impose real user costs relative to the innovations. The price adjustments reflect consumers' willingness to pay to achieve the relatively superior performance of the innovations.

More specifically, the index is constructed as the geometric mean of a Laspyres index—measuring consumer willingness to accept compensation to give up the gains from the innovation—and a Paasche index, measuring their willingness to pay to receive the gains from innovation. Both are measured relative to the baseline, and neither is theoretically superior to the other. The Tornqvist index is an equally weighted geometric average of the two.[3]

USING THE MODEL TO ESTIMATE CONSUMER BENEFITS FROM TWO ATP-FUNDED PROJECTS

We apply the cost-index model to estimate expected consumer welfare gains from two innovations in digital data storage (DDS), both funded by the ATP and proposed and implemented by two U.S. companies. Imation Corporation and LOTS Technology, Inc. are the innovators. Both technologies are expected to offer faster writing and retrieval of digital data, and one of them would offer a large increase in storage capacity as well. One of them would pioneer the use of optical tape, and the other would replace helical with linear scanning of magnetic tape.

The Imation Joint Venture: Tape and Cartridge System

Imation Corporation of Oakdale, MN, is leading a research joint-venture project begun in the fall of 1995, and scheduled to last five years. The joint venture received $10.4 million from the ATP, to which member companies added $10.7 million. Other members of the joint venture are Pergrine Recording Technology of St. Paul, MN; Seagate Technology, Inc. of Costa Mesa, CA; and Advanced Research Corp. of Minneapolis, MN. The joint venture seeks to develop technologies required for a small, reliable, affordable tape recording and cartridge system that will record data at rates greater than 30 megabytes per second, with an ultimate goal of 100 megabytes per second. The first major goal in the development of that system is to develop a linear tape drive that can match or exceed the performance and capacity of helical-scan systems currently in use.

[3] The theory of index numbers tells us that no single index satisfies all "desirable" properties or tests, e.g., tests related to scalability, transitivity, symmetry, and proportionality. The Tornqvist index satisfies many of the tests. For the mathematical formula we use to construct a Tornqvist cost index see our larger report from which this version is drawn, D. Austin and M. Macauley, *Estimating Future Consumer Benefits from ATP-Funded Innovation: The Case of Digital Data Storage*, NIST GCR 00-790, April 2000.

The LOTS Award: Optical Technology

LOTS Technology, Inc., of Sunnyvale, CA, received a single company award and began its two-year project in the fall of 1995. The company received nearly $2 million from ATP for its project, and put in approximately another million. The project goal was to develop an optical tape read/write technology capable of storing 1 trillion bytes (a terabyte) of information, and of transferring that data at a rate of at least 100 million bytes (100 megabytes) per second. This represents a 1,200-fold increase in capacity compared to the industry standard and a 100-fold increase compared to the next generation of cartridge storage tape drives currently being introduced.

ESTIMATING BENEFITS

We estimate how much better off consumers may be with these two innovations, as compared to staying with the existing or defender technologies which, as noted above, are assumed to continue to improve. We define the cost index relative to an aggressive baseline scenario where we assume that the best available performance of the defender technologies improves at the same rate as the innovations improve.

To calculate the index, we use a simulation model containing 18 parameters, all but two of which are drawn from estimated probability distributions. We directly observe current prices and performance of the defender technologies, but we must forecast the initial values they will take in the model because the innovations, as of late 1999, had not yet been introduced, and the model's initial period is linked to the introduction of the new products. Our price and performance forecasts for the new products reflect the innovators' target, both at introduction and two-to-five years ahead. We assume that these targets reflect some "pioneer project bias"—a tendency for innovators to be overly optimistic about their projects. We make allowances for this by putting extra weight on potentially "disappointing" outcomes with respect to expected growth in market size, adoption rates, prices, and performance of the innovations.

In contrast to our conservative treatment of the innovations, we use nonconservative assumptions in estimating the performance of the defender technologies. We make our forecasts for the parameter values on the basis of recent trends in leading DDS devices. To further provide a conservative estimate of consumer benefits for the ATP-funded innovations, we assume that the prices of the existing products will decline at the same rate as for the innovations.

We estimate the shadow values by hedonic regression analysis of recent retail prices and performance characteristics. These regressions also produce estimated standard errors, which we use to construct the initial-period probability distributions for the shadow values. For the other parameters, we must use *ad hoc* rules of thumb for estimating the uncertainties. Again for a more conservative estimate, we assume less uncertainty for the existing-product parameters than for innovations, even in the later years.

Uncertainties

Uncertainties derive from three main sources: (1) manufacturing and market conditions can vary; (2) the data are imperfectly observed; and (3) future outcomes cannot be predicted with certainty. Sensitivity tests reveal those parameters that are most important and indicate where it is necessary to test the results using alternative values.

RESULTS

Our analysis shows that both the linear scanning technology and the optical tape, if successfully introduced, are expected to generate large consumer benefits.

Estimated Benefits

Linear Scanning

We estimate that the linear scanning technology, if successfully introduced, will yield $2.2 billion (median value) in present value consumer benefits over a five-year period, relative to the best existing technology. (Benefits from the probability distribution ranged from $1.3 billion to $3.2 billion between the 5^{th} and 95^{th} percentiles.) Figure 2 shows how the gains from linear scanning technology are expected to accumulate over our five-year forecasting window.[4]

Optical Tape

We estimate that the optical tape technology, if successfully introduced, would yield $1.5 billion (median value) in present value consumer benefits over five years relative to the best existing technology. (Benefits from the probability distribution ranged from $1.1 billion at the 5th percentile, to $1.9 billion at the 95th percentile.) Figure 3 shows how the gains from the optical tape technology are expected to accumulate over the same five-year forecasting window.[5]

These estimates of benefits are very large even though it is assumed that the existing (defender) technology improves at a rate faster than historical rates. Furthermore, the estimates do not include benefits resulting from knowledge spillovers or from second-generation projects. On the other hand, if disk drive arrays

[4] Under our assumption that the new DDS technologies would not have been developed within this five-year period without ATP assistance, these benefits can be attributed to the ATP.

[5] Please note the difference in scale.

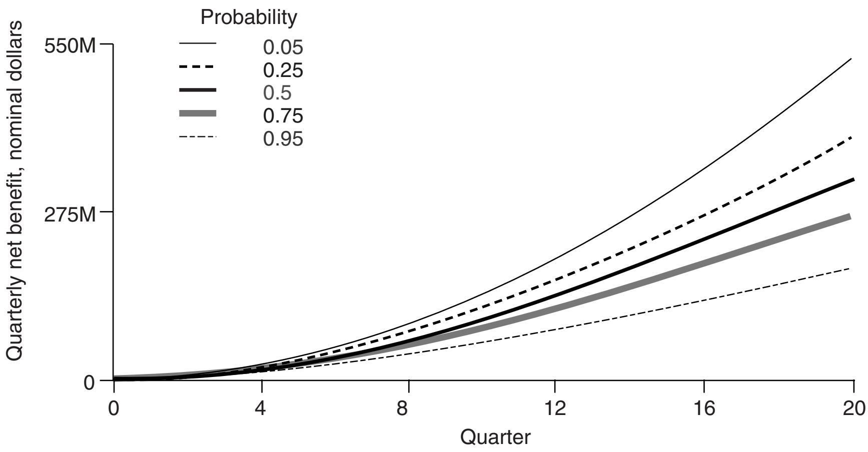

FIGURE 2 Consumer benefit given successful introduction: Linear scanning innovation vs. defending products

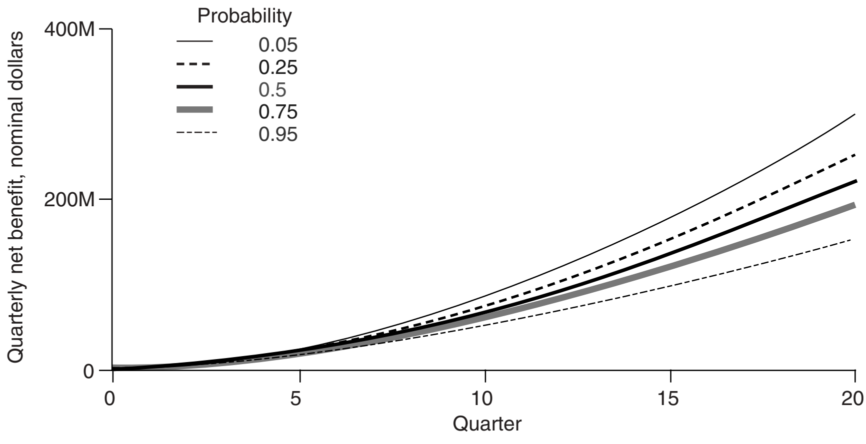

FIGURE 3 Consumer benefit given successful introduction: Optical tape innovation vs. defending products

continue to make inroads into traditional tape storage markets, actual benefits will likely be lower than expected.

We find the benefits estimates to be relatively insensitive to changes in the performance parameters, and somewhat more sensitive to price and rate of adoption data. However, within the expected range of parametric values, the results are robust.

TABLE 1 DDS Innovations, Present Value of Consumer Welfare Gains over Five Years ($ billions, 2000)

Percentile	Linear Scanning	Optical Tape
5th	1.25	1.05
25th	1.79	1.30
Median	2.16	1.45
75th	2.53	1.62
95th	3.17	1.88

CONCLUSIONS

Our analysis has shown that gains in consumer benefits from ATP investments in digital data storage are likely to be substantial. If these DDS technologies would not have been developed without ATP assistance, our estimates measure gross early-commercialization benefits attributable to the ATP. Even if other, failed investments by ATP in DDS technology were included, just one success on the scale of our forecasts would outweigh the ATP's total annual investments in all areas of technology.

Sensitivity analysis, in which we test the results to changes in the value of parameters, demonstrates the robustness of the basic conclusions. Where greater precision is desired, model simulations reveal the most important sources of uncertainty in the final benefit estimates, suggesting where additional research on the true values of individual parameters might be cost effective.

Uncertainties and omissions may cause actual outcomes to differ from the forecasts. We did not include benefits from knowledge spillovers or follow-on improvements in this study. If knowledge spillovers occur, our benefit estimates here may be low. On the other hand, if disk drive arrays continue to make inroads into traditional tape storage markets, our benefit estimates will be high.

A Useful Tool for Comparison

The cost-index approach is a potentially useful tool for resource allocation by R&D managers in both the private and public sectors. Two of the model's strengths are that it incorporates uncertainty and it varies all of the parameters simultaneously, so that the implications of changes to the parameter values and assumptions can be seen within a unified framework. The model can be used to evaluate a single project's consumer benefits over time, and also to compare the future benefits of projects that may be competing for private-sector or government R&D funds.

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Perspectives on the Determinants of Success in ATP-sponsored R&D Joint Ventures: The Views of Participants[1]

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Brigham Young University

Benjamin C. Powell
University of Pennsylvania

OVERVIEW

This study explores the growing importance of collaborative ventures to the nation's economic strength, the difficulty in making them work, and the role of government in fostering collaborative ventures. Its focus is on factors that increase or decrease the likelihood of success of collaborations as seen from the perspective of participants in ATP-funded joint ventures in the automotive industry.

Key findings of this analysis are that factors fostering trust and information sharing, or decreasing coordination costs, improve the chances of success. Conversely, factors that negatively affect the level of trust and information sharing, or increase coordination costs, among the joint-venture participants adversely affect their success. Negative factors include an overly large number of participants within a given joint venture, a horizontally structured joint-venture organization populated by direct competitors, lack of experience of members working together, a lack of personnel stability, and a low level of company commitment. The importance of these factors varies depending on the circumstances (e.g., high turnover rates are more detrimental when small companies rather than large companies are involved).

This analysis also suggests that the ATP is accelerating and improving the successful outcome of collaborative projects that are taking on higher risk and

[1] Condensed version of forthcoming study by Jeffrey Dyer and Benjamin Powell, forthcoming, *Perspectives on Success and the Determinants of Success in ATP-Sponsored R&D Joint Ventures: The Views of Participants in 18 Automobile Manufacturing Projects*, GCR 00-803.

longer-term research than collaborative endeavors without government involvement. Moreover, the findings suggest that the ATP is providing funding during critical stages, overcoming barriers to collaborating, increasing project stability, and causing collaborative projects to run more smoothly, albeit with some perceived loss of flexibility on the part of companies. Due to the relatively small sample size and the exploratory nature of the study, the results are considered suggestive rather than conclusive, and a more extensive follow-on study is proposed.

COLLABORATION: IMPORTANT AND DIFFICULT

Innovation is critical to superior performance for companies in high-technology industries. To produce innovations, companies increasingly seek collaborative relationships to access complementary resources, capabilities, and knowledge outside the firm.[2] The past two decades have witnessed an extraordinary increase in the number of inter-firm collaborations, i.e., alliances or joint ventures among firms. Indeed, Anand and Khanna observe that alliances have become one of the most important organizational forms, with more than 20,000 alliances reported in just the last two years.[3]

Despite their potential importance, inter-firm collaborations are difficult to manage. Some estimates suggest that approximately 30-70 percent fail.[4] Alliances may be mushrooming in numbers, but alliance success is difficult to attain.

Understanding how to enhance the probability of success in inter-firm collaboration would be extremely valuable from an economic standpoint. This study increases such understanding by identifying factors held by companies participating in ATP-funded joint ventures to be particularly important to success.

GOVERNMENT AS A CATALYST FOR COLLABORATION

Recent research suggests that government can play an important role as a catalyst for inter-firm collaboration.[5] Not only can government play an important

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[2] D. J. Teece et al., "Dynamic Capabilities and Strategic Management," *Strategic Management Journal*, 18(7):509-533.

[3] B. N. Anand and T. Khanna, "Do Firms Learn to Create Value? The Case of Alliances," *Strategic Management Journal*, Special Issue Conference, Northwestern University, 1999.

[4] B. Kogut, "The Stability of Joint Ventures: Reciprocity and Competitive Rivalry," *Journal of Industrial Economics*, 38(2):183-98; J. Bleeke and D. Ernst, "Is Your Strategic Alliance Really a Sale?" *Harvard Business Review*, 73(1):97-105; Alliance Analyst, *Managing Alliances—Skills for the Modern Era*, March, 18, 1996; and K. R. Harrigan, *Strategies for Joint Ventures*, New York: The Free Press, 1985.

[5] W. G. Ouchi and M. K. Bolton, "The Logic of Joint Research and Development," *California Management Review*, 30(3):9-33, 1988; and M. R. Kelly and C. R. Cook, *The Institutional Context and Manufacturing Performance: The Case of the U.S. Defense Industrial Network*, NBER Working Paper W6460, March 1998.

role in facilitating R&D collaboration, some researchers argue that under some conditions the government's involvement in facilitation collaboration may be critical to success.

The appropriate role of government in innovation depends at least in part on the nature of the intellectual property to be developed. According to Ouchi and Bolton, intellectual property that is "private property" can be effectively developed by private firms, whereas "public property," and, what they call, "leaky property" require collaborative arrangements.[6] Ouchi and Bolton see university and government laboratories as well suited for developing public property, and inter-firm collaboration as a more effective means of producing leaky property because single firms acting alone will not be willing to do it due to risk and difficulties in appropriating sufficient benefits.

Ouchi and Bolton argue that without sufficient inter-firm collaboration society will fail to provide an adequate level of leaky property, and, as a consequence, the nation will be at a disadvantage relative to other nations in international competition. The problem can be avoided or alleviated, they argue, if the government plays a key role in facilitating multi-firm industry collaboration needed to produce this type of intellectual property.

One way that government can help overcome the lack of appropriate institutional forms is to provide a forum for firms to gain experience with collaborative innovation through government-funded research programs. Studies show a positive relationship between alliance experience and future alliance success.[7] By participating in government-sponsored multi-firm collaborations, companies increase their alliance experience and their capability at managing alliances. These studies suggest that government intervention to catalyze inter-firm collaborative innovation could be socially beneficial. By identifying opportunities to develop leaky property and by funding inter-firm collaboration to pursue these opportunities, governments could assist firms in developing knowledge and capabilities that have value to society that exceeds the funding costs.

STUDY METHODS

In preparation for this study, we established a general theoretical framework, but refrained from specifying hypotheses in advance. We conducted semi-structured interviews of companies participating in the 18 ATP-funded joint ventures listed in Table 1.

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[6] W. G. Ouchi and M. K. Bolton*, The Institutional Context and Manufacturing Performance, op. cit.*.

[7] Anand and Khanna, "Do Firms Learn to Create Value?", *op. cit.*; Kelley and Cook, "The Institutional Context and Manufacturing Performance: The Case of the U.S. Defense Industrial Network," forthcoming as an NBER Working Paper, 1998; and P. J. Kale, J. H. Dyer, and H. Singh, *Alliance Capability, Stock Market Response, and Long Term Alliance Success*, paper presented at Academy of Management Conference, Toronto, 2000.

TABLE 1 ATP Projects Included in the Study

Number	Project Name
91-01-0083	NCMS Rapid Response Manufacturing
91-01-0177	Development of Advanced Technologies and Systems for Controlling Dimensional Variation in Automobile Body Manufacturing
93-01-0244	Strategic Machine Tool Technologies: Spindles
94-01-0178	Rapid Agile Metrology for Manufacturing
94-02-0027	Automotive Composite Structures: Development of High-Volume Manufacturing Technology
94-02-0030	Polymer Matrix Composite Power Transmission Devices
95-02-0008	Agile Precision Sheet-Metal Stamping
95-02-0013	Intelligent Resistance Welding
95-02-0026	Flexible Low-Cost Laser Machining for Motor Vehicle Manufacturing
95-02-0035	Springback Predictability in Automotive Manufacturing
95-02-0036	Plasma-Based Processing of Lightweight Materials for Motor-Vehicle Components and Manufacturing Applications
95-02-0058	Flow-Control Machining
95-02-0062	Fast, Volumetric X-Ray Scanner for Three-Dimensional Characterization of Critical Objects
97-02-0018	Flexible Robotic Assembly for Powertrain Applications (FRAPA)
97-02-0028	Sub-Micron Precision Grinding of Advanced Engineering Materials
97-02-0047	Nanocomposites New Low-Cost, High-Strength Materials for Automotive Parts
97-02-0055	Development of the 3D Printing Process for Direct Fabrication of Automotive Tooling for Lost Foam Castings
94-01-0079	Engineered Surfaces for Rolling and Sliding Contacts

To increase comparability, the joint ventures included in the study were restricted to those focusing on technologies having potential applications in the automotive industry. Each of them had invested $5 million or more, with approximately half of the funding provided by the ATP. Five of the joint ventures were funded in ATP General Competitions, open to all technologies, and 13 were funded in ATP Focused Competitions where automotive manufacturing was the area of focus. The sizes of the joint ventures varied from 2 to 21 members. All of them had been in existence for at least one year. Twelve of the 18 were still underway and six were completed (or terminated before the designated completion date).

Our interview discussions centered on the following questions:

1) How would you define success in a venture like this? What makes one joint venture more successful than another?
2) Is achieving the technical and commercialization objectives proposed to the ATP a good measure of success? Did the joint venture achieve these objectives?
3) What factors influenced the success or failure of the joint venture? What are the barriers to success? What are the enablers?

4) What was the role of the ATP in this joint venture? Did the ATP have any influence beyond the provision of funding?

From the results of the interviews, we formed tentative hypotheses about the determinants of success that we report here. We propose in the future to subject these hypotheses to further testing by administering a survey to a broader group of subjects.

WHAT CONSTITUTES SUCCESS FROM THE PERSPECTIVE OF PARTICIPANTS?

In order to discuss the determinants of success, we sought to define how the joint-venture participants thought about success. We discovered that the company representatives typically discussed their views of success in terms of the following five categories:

(1) achievement of technical objectives;
(2) commercialization of the technology;
(3) generation of patents (for some but not all ventures);
(4) formation of networks of relationships; and
(5) generation of unanticipated benefits, such as acquisition of unanticipated technical knowledge.

The most successful ventures were considered those that met the technical objectives (including generating patents) and produced a new technology worthy of commercialization. Stated one participant, "Certainly one measure of success is whether or not we were able to meet the technical objectives we laid out at the beginning of the program. But an even more important measure of success is whether or not the technology resulted in a commercializable product." However, participants also deemed ventures somewhat successful if they generated benefits that were not directly related to the ATP technical objectives. An example of a partial success is a venture that resulted in relationships with other firms that resulted in other ventures or business opportunities, unexpected technologies, and knowledge that convinced the firm to move in different technology directions.

Not surprisingly, companies tend to equate joint venture success with benefits to themselves, but even similar benefits can translate into different levels of perceived success because of different weightings. Our analysis of success from the perspective of participants suggests that companies in R&D joint ventures apply similar criteria but different weightings in assessing joint venture success.

It should be noted that participants gave varied responses, and we caution that the definition of joint-venture success and the factors influencing its attainment are complex and difficult to measure. Not unexpectedly, in some cases members of the same joint venture differed dramatically in their views about the degree of success attained.

Determinants of Success

Our interviews revealed a variety of factors that influence the performance of ATP joint ventures. At a basic level, we found that more successful joint ventures were characterized by (1) greater knowledge sharing among participants, and (2) more effective coordination (lower coordination cots) among participants. There were a variety of factors that influenced the willingness or ability of joint venture partners to share knowledge, e.g., the extent to which the participants trusted each other, and a variety of factors that influenced the cost of coordinating the venture's activities.

Figure 1 captures participant responses about what determines success. It is a path diagram that shows the key factors that participants said influenced their joint-venture success or lack thereof, the direction and nature of impact, and the linkages from these factors to outcome success measures. The first set of circles on the left contains five of the factors that participants said influence their collaborative success. On the right-hand side of the figure is the participants' list of success measures. The two characteristics that the more successful joint ventures exhibited—(1) greater knowledge/information sharing and (2) lower coordination costs among participants—are shown in the center of the figure, together with "trust," which is closely linked to information sharing. These are the key mechanisms through which the five factors influence success.

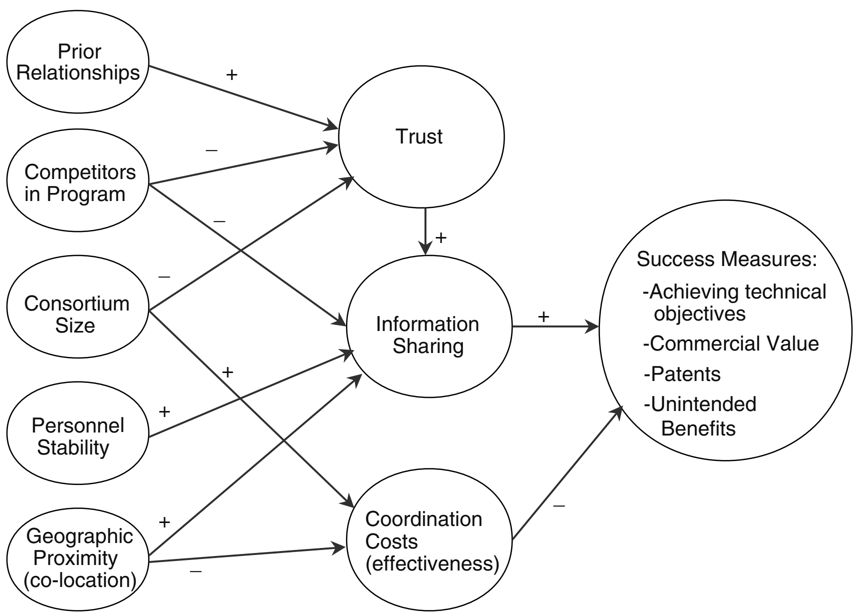

FIGURE 1 The determinants of success in ATP-sponsored joint ventures

The greater the trust, the more the information sharing, and the greater is the likelihood of a successful outcome. The higher the coordination costs, in contrast, the lower the likelihood of a successful outcome. Reading from left to right along the directional lines, the plus and minus signs reveal the nature and direction of impact. Each factor contributes to, or detracts from—or both contributes to and detracts from—success.

Prior Relationships Matter

Thus, prior relationships have a positive influence on trust, which in turn has a positive impact on information sharing, and this in turn positively affects joint-venture success. In contrast, the presence of competitors is shown to detract from trust and from information sharing, and, hence, negatively affects joint-venture success. (Findings, however, also suggest that the ATP program facilitates the development of relationships among direct competitors beyond what they otherwise would have been, which may be considered a positive influence on this otherwise negatively perceived factor.)

Consortium Size and Proximity

Increasing consortium size is negatively associated with trust building and positively associated with the higher coordination costs, a negative effect. Greater personnel stability (lower turnover) is positively associated with information sharing and, hence, positively associated with success. Geographic proximity (co-location) is positively associated with the act of information sharing and, hence, positively linked to success. Geographic proximity has a reducing effect on coordination costs and, hence, a positive association with success (shown by the two negative signs linking these directional arrows).

Motivation, Management, and Sharing

We found several additional factors that the joint-venture participants think influence the success of their collaboration. One of these is the degree of member motivation—the stronger the motivation the more successful the project is likely to be. Another factor is whether there is a technology leader or product champion to drive the process, particularly a potential customer who exhibits strong interest in future products or processes embodying the new technology. An additional factor is the use of a hired project manager. Despite the high cost of using professional project management, the interviewees saw it as worthwhile. A final factor identified by the authors as important, particularly to the successful launch of a joint venture, is satisfactory agreement over the protection and sharing of property rights.

ATP'S CONTRIBUTION: BETTER ACCELERATION, STABILITY, AND ORGANIZATION

Joint-venture participants reported several ways that the ATP has contributed to the success of their joint venture. By funding riskier and longer-term projects than non-government sponsored projects tend to be, the ATP accelerates this particular type of project. As one participant noted, "I think ATP accelerates the development of high risk technologies."

Another effect the participants attributed to the ATP was to gain for the projects it funds increased commitment from top management and, hence, greater project stability. This was said to lower internal monitoring and budgeting costs because the project is not constantly being re-evaluated. Participants involved in the day-to-day operations of the joint ventures valued the increased company commitment of time, funds, and resources because it allowed them to do long range planning. Though positive for staying on schedule and the success of the project, this greater commitment was said also to reduce company flexibility to change its plans and redirect resources.

The interviews revealed another potential role for ATP in the seeding of joint ventures, that is, carrying them through particularly difficult periods in their life cycles. According to one participant, a major joint venture would not have survived without ATP's funding. In the participant's words, "[the ATP] really did help us get through a tough spot."

Reportedly the ATP's involvement helps to break down barriers to collaboration. Some participants felt that there were barriers to collaboration in the U.S. automotive industry, and the ATP played a role in overcoming these barriers.

A related effect may be to help new organizations through the difficult period associated with newness. Just as firms must overcome a "liability of newness,"[8] so too do new research joint ventures face a similar obstacle, or, as a more recent organizational form, a greater liability.

Another role that the ATP was found to play is to transform what is usually an iterative and *ad hoc* innovation process into a more goal-directed and organized project. It does this primarily through its demanding application process. As one respondent stated, "if all we did was write the proposal, it would be valuable." Yet another participant described the application process as "both a plus and a negative," mentioning on the negative side the time required to prepare it and the difficulty experienced by "a regular person" in preparing the application. But, once the application process is completed, participants generally felt that the large amount of up-front planning led to smoother running joint ventures.

We found little evidence of an active role for the ATP project manager in the structure or management of the ATP joint ventures (though this may reflect the

[8] M. T. Hannan and J. H. Freeman, "Structural Inertia and Organizational Change," *American Sociological Review*, 49(2):149-164, 1984.

individual project managers in the technical areas studies). Yet, in some cases the technical expertise of the ATP project manager did seem to be important in the initial stages of joint venture formation. According to one participant, preparing applications is an expensive and time-consuming process. As a result, companies are only willing to go through this process if: (a) they know their applications will be reviewed by someone who understands it and can provide valuable feedback, and (b) they believe there is a high probability of acceptance.

CONCLUSION

While we found that participants generally agreed on the dimensions of success, they placed different weights on these dimensions. Based on study findings, we recommend the use of multi-dimensional measures of success for monitoring success in ongoing, R&D joint ventures.

We found that participants stressed four factors—prior experience, number of direct competitors, number of participants, and personnel stability—that affect knowledge sharing and coordination costs in managing the joint ventures. More specifically, we found that:

- Joint ventures where the participating firms have had prior collaborative experience with other joint venture members are more successful.
- Joint ventures with too many participants (i.e., more than 8) are less successful. (Or alternatively, there is a curvilinear relationship between the number of participants and the degree of project success; projects with too few, or too many, participants are less successful).
- Joint ventures with direct competitors (i.e., horizontal joint ventures) are less successful than joint ventures without direct competitors (i.e., vertical joint ventures). (It is also possibly a bimodal distribution; collaboration with competitors may turn out to be either very unsuccessful or very successful.)
- Joint ventures with low personnel turnover are more successful.

There appear to be important contingencies operating on the determinants of performance. For example, turnover was a major issue in most R&D joint ventures, but when the lead organizations in the R&D joint ventures possessed large, established R&D groups, turnover was not mentioned as an issue. Similarly, turnover seemed to have a more detrimental impact on joint venture performance when it occurred in younger joint ventures and in small firms.

The exploratory methodology applied in this study has been more suggestive than conclusive. Our analysis of the interviews we conducted provides insight, but our findings can not be considered conclusive. There are two major disadvantages to the exploratory approach of this study that future research could address: (1) The exploratory approach relies heavily on the perceptions of participants to disentangle complex causal relationships; and (2) the results cannot be used to generalize to the entire population of ATP R&D joint ventures. A more comprehensive study that includes statistical analysis of a large sample could verify and extend the findings of this study.

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Taking a Step Back: An Early Results Overview of Fifty ATP Awards

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SUMMARY

This report reviews and rates the performance of the first 50 projects that have completed their ATP-funded research, several years after completion. It develops and applies a four-star rating system to assess project progress toward achieving ATP's goals in light of the outputs of each of the completed projects.

Top Performers

For a group of top performers, it examines net benefits and their implications for the overall success to date of the ATP. Findings are that 16 percent of the completed projects scored in the top category in terms of overall effectiveness. The top performers tended to be strong in solving challenging technical problems, making the new technical knowledge available to others, and directly using that knowledge to accelerate commercial use of the technology—three dimensions of performance that figure prominently in achieving the long-run success of the ATP. Half of them received awards for their technical accomplishments from outside parties, and more than half of the single-company leaders received outside recognition for their business accomplishments. All of the top performers had collaborative relationships, and attracted private capital for their follow-on commercialization efforts. All of the single-company leaders in the group expanded their employment substantially. And, all of them have a very strong outlook for continued progress.

Low Performers

Twenty-six percent of the 50 projects were in the bottom group of performers. Although most of these produced technical outputs such as patents or papers, none of them were award-winning; all showed little or no further direct progress toward commercialization; and the outlook for the future through direct action of the award recipients was poor or uncertain at best.

Middle Performers

Most of the 50 projects (58 percent) fell in the middle group of performers—they produced solid technical accomplishments but overall were not as strong as the top group. In some cases, these projects were strong technically but had not demonstrated robust commercial progress, and, in a few cases, they had produced a technology with commercial strength but had little else to show in the way of sharing knowledge with others—a public-interest goal of the program.

Portfolio Perspective

From a portfolio perspective, the results look strong for the ATP: the estimated net benefits attributed to the program from the top performers of the first 50 completed projects exceed the cost of the entire program to date, suggesting that the program is on track to produce a high return for the nation.

Caveat

These positive results are subject to an important caveat: The projects were assessed in two different groups in two different periods—38 of the projects were assessed two years ago and 12 more recently. Given that technology development and commercialization take time and are characterized by unexpected breakthroughs and failures, future updates of these projects may alter the findings reported here.

SIGNIFICANCE OF THE FIRST 50 PROJECTS

From the moment the ATP funded its first group of 11 projects in the 1990 competition, program administrators, the Administration, Congress, technology policy makers, industry, and others in this country and abroad were keenly interested in the outcome. But technology development and commercialization are lengthy processes, and it takes time to produce results. Now, as the program completes its first decade of operation, there are a growing number of projects that have completed their ATP-funded research and moved into the post-project period. This group of completed projects makes it possible to measure project outputs, assess project progress and outlook, develop composite performance metrics, compile statistics, and analyze the results for implications about overall program success. A partial step was taken toward this goal with the publication of a report in 1999 on the first 38 completed projects.[1] This report takes the next step, by extending coverage to 50 projects and adding composite performance metrics.[2]

PROJECT CHARACTERISTICS

Small Business Focus, with University Links

The majority (84 percent) of the first 50 completed projects are single-applicant projects, and most (70 percent) are led by small businesses. Although only 16 percent of the 50 projects are joint ventures, 84 percent of them had collaborative relationships. As shown in Table 1, nearly half the projects had close R&D ties with universities, and more than half the projects formed collaborative arrangements to pursue commercialization.

Technology Concentrations

By area of technology, the highest concentration (38 percent) is in *Electronics/Computer Hardware/Communications*, followed by *Manufacturing* (22 percent), *Biotechnology and Advanced Materials/Chemicals* (14 percent each), and *Information Technology* (12 percent).[3] These technology concentrations differ from those found in the larger ATP portfolio, where information technology is the largest single area, followed by Advanced Materials/Chemicals. Most of these were funded in ATP's General Competitions, whereas Focused Program Competitions gave rise to the majority of projects in the larger ATP portfolio.

Cost Sharing

As Table 2 shows, the ATP funded slightly more than half the $121.5 million of single-applicant total project research costs.[4] Joint ventures, though a minority of projects, received about 40 percent of total ATP funding. Together, the ATP

[1] See William F. Long, *Performance of Completed Projects: Status Report Number 1*, NIST Special Publication 950-1, March 1999.

[2] For the full report on the first 50 completed projects, upon which this paper is based see Rosalie T. Ruegg et al., *Performance of 50 Completed Projects*: *Status Report Number 2*, NIST Special Publication 950-2, forthcoming.

[3] The ATP classifies its projects into these five technology areas according to where the major technical challenges lie. In fact, most projects cut across technology areas.

[4] The ATP cost share is higher for this group than overall because a high percentage of the single-applicant projects were led by small businesses with very low overhead which is the portion of costs that must be covered by industry.

TABLE 1 Collaborative Activity

Type of Collaboration	Number of Projects	Percentage
Collaborating on R&D with other companies or non-university organizations	21	42
Close R&D ties with universities	24	48
Collaborating on R&D with other companies or non-university organizations OR close R&D ties with universities	33	66
Collaborating on commercialization with other organizations	27	54
Collaborating in one or more of the above ways	42	84

and industry spent a total of $208 million on the 50 projects, with the ATP paying slightly less than half the total of project costs. The ATP spent an average of $1.5 million per single-applicant project and an average of $4.9 million per joint-venture project. Across the 50 projects, the average total cost (ATP + industry) per project was $4.2 million, and the median project length was three years.

STUDY APPROACH: 50 MINI-CASE STUDIES

At the core of the study from which this paper is drawn are 50 mini-case studies covering each of the completed projects. Each of these briefly tells the project story, recounting its goals and challenges, describing the innovators and their respective roles, and assessing progress to date and the future outlook.

Although the particulars vary for each project, certain types of data are systematically collected for all of them. Consistent with ATP's mission, the evaluation focuses on collecting data related to the following dimensions of performance.

- ***Knowledge creation and dissemination***, which is assessed using the following data: recognition by other organizations of a project's technical

TABLE 2 ATP Funding, Industry Cost Share and Total Costs of 50 Completed Projects

Type of Project	ATP Funding ($million)	Industry Cost Share ($millions)	Total Project Costs ($millions)	ATP Share of Costs (Percent)	Industry Share of Costs (Percent)
Single-Applicant Projects	64.5	57.0	121.5	53	47
Joint-Venture Projects	39.5	47.0	86.5	46	54
All Completed Projects	104.0	104.0	208.0	50	50

accomplishments; numbers of patents filed and granted; citations of patents by others; publications and presentations; collaborative relationships; and knowledge embodied in and disseminated through new products and processes.

- ***Commercialization progress***, which is tracked in terms of attraction of additional capital for continued pursuit of project goals, including resources provided by collaborative partners; entering the market with products and services; employment changes at the small-companies leading projects, and other indicators of growth; awards by other organizations for business accomplishments of project leaders; and the analyst's assessment of the future outlook for the technology based on all the information collected.[5]
- ***Overall project effectiveness.*** The approach is to compile all of the data for all of the projects, and to compute aggregate statistics of interest across the set of 50, such as the total number of patents and the percentage of projects whose technologies have been commercialized. Composite scores of overall project performance are constructed by combining output data for knowledge creation, knowledge dissemination, and commercialization, and outlook.[6] The output data and the composite performance score allow one to see at a glance how a project has performed thus far in terms of the two paths by which ATP delivers benefits to the nation: (1) the indirect path which relies on knowledge transfer from the innovators to others who in turn may use the knowledge for economic benefit, and (2) the direct path by which the U.S. award recipient/innovators directly pursue commercialization of the newly developed technologies.[7]

Data for the 50 projects were collected from ATP project records, telephone interviews with company representatives, interviews with ATP project managers, independent sources such as Hoovers Online Company and Industry Network, company web sites, the U.S. Patent Office, and in-depth project studies performed by other analysts.

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[5] ATP has long reported certain of these data to meet requirements of the Government Performance and Results Act (GPRA) for project metrics, such as numbers of patents and publications, and number of technologies commercialized. The GPRA is a legislative framework for requiring federal agencies to set strategic goals, measure performance, and report on the degree to which goals were met. An overview of the GPRA is provided in Appendix 1 of the General Accounting Office Executive Guide, *Effectively Implementing the Government Performance and Results Act*, Report no. GGD-96-118, Washington, D.C.: Government Accounting Office, 1996.

[6] The methodology for developing consolidated project performance metrics was developed and applied to the first 50 completed projects by Rosalie T. Ruegg, TIA Consulting, and is described by her in greater depth in the full report on which this paper is based.

[7] See Rosalie T. Ruegg's presentation in the proceedings of this volume, Panel II, for a description and illustrations of the direct and indirect pathways of ATP-project impact.

A Snap-Shot of Progress

The cases provide a snap shot of progress as of several years after the end of the ATP-funded project. Although all of the cases were performed about the same length of time after the ATP funding was completed, they may capture different stages in technology development. Information technology projects, for example, usually move faster from research to commercialization than do advanced materials and chemical projects, and, hence, may be expected to be further along several years after the ATP-funded research project is completed.

Another difference among the cases is the date they were performed. There are two groups: (1) 38 projects were assessed between 1997 and late 1998, and (2) 12 projects were assessed over 1999 and early 2000.[8] Since developments continue to unfold for most of these projects, the earlier set of 38 may have changed significantly since the data were collected. Indeed, the 12 may also have changed.

Future studies may add mini-cases for additional completed projects to this group of 50, also performed several years after completion; and future studies may also update these studies by reviewing the projects' progress over time.

PROJECT PERFORMANCE: KNOWLEDGE CREATION AND DISSEMINATION

Each of the 50 completed ATP projects targeted a number of specific technical-knowledge discovery goals designed to achieve a new or better way of doing things.[9] The knowledge created by each project is the source of its future economic benefit, both for the innovator and for others who acquire the knowledge. It is a good starting place for assessing completed projects.

Knowledge gains by the 50 projects range from mathematical algorithms underlying new software tools, to the science of growing human tissue, to new techniques for fabricating high-temperature superconducting devices, to new chemical formulations. The diversity reflects the fact that all but two of the projects were funded in the ATP's General Competitions, which cast a wide net for ideas regardless of technology area.[10]

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[8] William F. Long collected the data for the first 38. Jonathan Tucker, Chris Hansen, Josh Rosenberg, Jon Dryfus, Benjamin Fletcher, Kathleen McTigue, Michael Walsh, Mariah Tanner, and Karen Seeh collected the data for the next 12, supplemented by data collected by Rosalie T. Ruegg.

[9] In establishing the ATP, Congress directed that it add to the nation's scientific and technical knowledge base.

[10] ATP also funded "Focused Program" competitions from 1994-1998 that funded certain areas in greater depth. Projects from these competitions will appear in larger numbers in subsequent studies of completed projects.

TABLE 3 Outside Recognition of Technical Achievements of the First 50 Completed Projects

Project Awardee	Year	Awarding Organization	Award
American Superconductor	1996	R&D Magazine	One of the 100 most important innovations of the year.
American Superconductor	1996	Industry Week magazine	Technology of the Year award.
Communication Intelligence #1	1997	Arthritis Foundation	"Ease-of-Use Seal of Commendation" for the development of natural handwriting technology, for use by disabled people who have trouble with keyboard entry.
DuPont	1993	Microwave & Rf magazine	One of the Top Products of 1993, for high-temperature superconductivity component technology.
Engineering Animation	1994	Computerworld magazine	Smithsonian Award, for the use of information technology in the field of medicine.
Engineering Animation	1995	Association of Medical Illustrators	Association of Medical Illustrators Award of Excellence in Animation
Engineering Animation	1995	International ANNIE Awards	Finalist, received together with Walt Disney, for best animations in the film industry.
Engineering Animation	1996	Industry Week magazine	One of the 25 Technologies of the Year, for interactive 3D visualization and dynamics software used for product development.
HelpMate Robotics	1996	Discover magazine	One of 36 finalists for Technology of the Year, for the HelpMate robot used in hospitals.
HelpMate Robotics	1997	Science Technology Foundation of Japan	Japan Prize, to CEO Joseph Engelberger, for "systems engineering for an artifactual environment."
Illinois Superconductor	1996	Microwave & RF magazine	One of the Top Products of 1996, for cellular phone site filters and superconductoring ceramics.

TABLE 3 *Continued*

Project Awardee	Year	Awarding Organization	Award
Illinois Superconductor	1997	American Ceramic Society	Corporate Technical Achievement Award.
Integra LifeSciences	1999		Thomas Alva Edison Award.
Molecular Simulations	1996	Computerworld magazine	Finalist for Smithsonian Award, the 1996 Innovator Medal.
NCMS	1994	Institute for Interconnecting & Packaging Electronic Circuits	Best Paper of Conference Awards.

Outside Recognition

There are a number of indicators that new knowledge has resulted from the R&D effort.[11] One that provides an early signal of the significance of the advance is recognition by outside parties. Table 3 lists awards that recognize the significance of technical accomplishments of this first group of 50 projects.

Patents

Patents, publications and presentations, as well as new and improved products and processes, not only indicate that new knowledge has been created, but also provide a relatively convenient means for others to acquire the knowledge. All but one of the 50 projects produced one or more of these outputs, indicating that they both created technical knowledge and provided a means of disseminating it.

Citations

Twenty-six of the 50 had filed a total of 115 patents at the time they were studied, 64 of which had been granted. And, other organizations were citing these patents, in some cases heavily. Patent citations are of particular interest because they signal the intensity of interest in an innovation and the intensity of its dis-

[11] Assessing the degree of significance of scientific and technical knowledge gained from the projects is a daunting task. Even those projects that were not fully successful in achieving all of their research goals, or those that have not been followed by strong progress in commercialization, have achieved knowledge gains that may eventually prove to be of great value. Here the approach taken to suggest significance is to rely on outside recognition by other organizations that see value in the knowledge, to examine the use of the knowledge by others as signaled by patent citations, and to look downstream to its unfolding value in use.

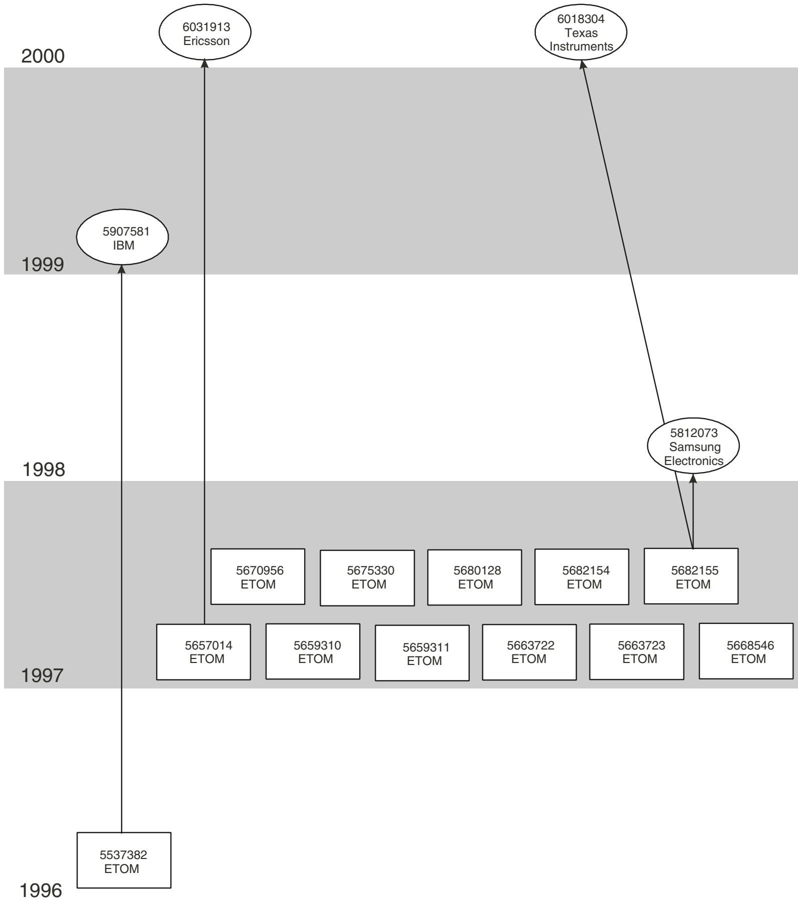

FIGURE 1 Patent tree for the ETOM project: The knowledge is disseminating although the company went bankrupt

semination. Figure 1 illustrates a "patent tree"[12] for three of 12 patents granted to ETOM Technologies, Inc., an award recipient that went bankrupt soon after the end of its ATP project. It demonstrates that the knowledge created can survive and spread even if the award recipient fails, an important point of ATP's two pathways (direct and indirect) to impact.

[12] Each published patent contains a list of previous patents and scholarly papers which establish the prior art as it relates to the invention. The citations provide a way to track the spread of technical knowledge through patents granted to ATP-funded projects. By following the trail of patent citations in subsequent patents back to the patents granted to the ATP-funded projects, it is possible to construct what looks much like an inverted genealogy tree. The patent trees were constructed under the direction of the project leader, Darin Boville of ATP's Economic Assessment Office.

Publications

Participants in more than half of the 50 projects published their research in technical and professional journals or presented papers in public forums, or both. Altogether, they published at least 180 papers and presented 245 or more papers, providing another way for others to learn about their research findings.

Collaboration

The extensive collaborative activities among these projects provided another avenue for the spread of new information. As was shown by Table 1, most (84 percent) of these projects entailed collaborations with others, including other companies, universities, national laboratories, non-profit consortia, and other organizations and individuals.

New Products

New and improved goods and services entering the marketplace also signal that the R&D has produced results, and, at the same time, often enable buyers to learn a great deal about the technology. For more than 60 percent of the projects, commercial products or processes based on the ATP-funded technology had reached the market, providing others with the ability to collect information about the new technologies through use, examination, and reverse engineering.

Public Meetings

The ATP organizes and sponsors numerous public workshops, where companies present non-confidential aspects of their ATP-funded research and engage in open discussions. These workshops facilitate information flows in several directions—among ATP award recipients and from them to other companies, ATP project managers, other government program managers, the press, potential investors, and universities. The ATP also makes project information available on its internet web site (http://www.atp.nist), and adds new non-proprietary project descriptions as new awards are made. Evaluation reports, such as this one, are an additional source of information to the public about the projects.

COMMERCIALIZATION: PUTTING KNOWLEDGE TO USE

If the new knowledge is to yield economic benefits to the nation, the award recipients who develop it, their collaborators, or other companies who acquire it, must put it to use. A second focus of this study is on commercialization progress of the award recipients, that is, progress along ATP's direct path of project impact. This is the path by which ATP is best able to accelerate the use of the technology by U.S. companies, the indirect path of knowledge dissemination being less subject to influence.

Companies in 39 of the 50 projects either had one or more products or processes in the market or expected to shortly. Table 4 shows that 80 total products and processes were commercialized already or expected soon.

Although commercializing a technology is an important step, it does not mean that the project is necessarily headed toward full success from the perspective of either the company or the ATP. In some cases products have been sold in relatively small number for testing and evaluation, and do not yet have a significant market. In several cases, struggling companies made small sales and subsequently failed due to cash-flow problems. Moreover, the early products and processes often embody partial aspects of the technology, as companies—particularly small ones—hurry to establish a revenue stream that they need for survival, while they continue to work toward larger objectives.

Real Commercial Products

Whether or not widespread diffusion of a technology ultimately results from commercial activities of award recipients remains to be seen in most cases, but it is highly significant that products and processes are actually on the market. This is an extremely important step for the eventual generation of broad-based economic benefits from the new technical capabilities. The bottom line is that despite the difficulty of moving from the research stage to commercialization, companies in 78 percent of the 50 projects either sold product, or used or licensed to others process improvements stemming from their research, or they were about to do so at the time they were contacted by study analysts.

Rapid Growth

An indicator that a small research-oriented company is on the path toward commercialization is company growth. A recent look at Fortune's *Fastest Grow-*

TABLE 4 Progress of Participating Companies in Commercializing the New Technologies

	Product/ Process on the Market	First Product/ Process Expected Soon	On the Market with Additional Product/ Process Expected Soon	On the Market or Expect Soon— Totals
Number of Projects	32	7	9	39
Number of Products/Processes	61	9	10	80

ing 100 Companies List found two of the 31 then-small companies on the list. Capitalized value of some of the companies has increased by hundreds of millions of dollars. Nearly a fifth grew their employment by more than 500 percent from the beginning of the project to several years after the project had completed, and 61 percent grew employment by more than 100 percent.[13] Several of the companies that were small when they received the ATP award, have grown out of that size category. Nineteen of the 31 small companies at least doubled in size; four companies grew more than 1,000 percent.

Not all the small companies grew—a little more than a fifth experienced no change or decreases in staff—but, as a group, the small companies funded by ATP grew rapidly as they parlayed their new technical capabilities into business opportunities.

OVERALL PROJECT PERFORMANCE

Figure 2 shows how the projects performed overall, where continuing progress is necessary for a high score.[14] At a glance, we can see from the ratings that the majority of the projects are still alive, in the sense that progress has been made and further progress appears likely. Sixteen percent of the projects were top performers in terms of overall project effectiveness. Fifty-eight percent were in the middle group. Twenty-six percent received low scores.

For these projects, progress signaled by the performance metrics is translating into benefits. Keeping in mind that the top scores represent a minority of the awardees, let us consider the estimated benefits of projects among the group of top scorers.

Medical Cost Savings

Three of the top performers developed medical technologies that were evaluated by economists at the Research Triangle Institute (RTI), a consulting firm in North Carolina.[15] RTI economists provided early estimates of the value of a new biopolymer to repair fractures, developed by Integra LifeSciences, a system for replicating stem cells, developed by Aastrom Biosciences, Inc., and a new prosthesis material—animal-derived extra-cellular matrix, or ADMAT, developed by Tissue Engineering, Inc.

[13] Employment changes in joint ventures, larger companies, and non-profit organizations are less closely tied to the success of individual research projects, and, their employment was not tracked.

[14] The composite overall scores were computed using all the raw inputs of knowledge creation and dissemination and commercialization progress. The latter were weighted more heavily such that only projects with continued progress by award recipients receive top scores.

[15] For a more detailed treatment of the RTI study see Taylor H. Bingham, "Estimating Economic Benefits from ATP Funding of New Medical Technologies," in this volume.

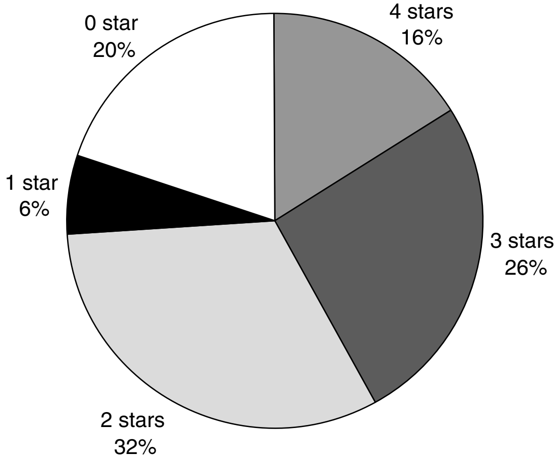

FIGURE 2 Distribution of projects by overall performance score

Biopolymer Repair

The RTI study estimated the medical cost savings from Integra's project in terms of avoiding second surgeries to remove implants, such as pins and screws, when trouble arises. It estimated benefits at $98 million, all attributed to the ATP.[16] Integra has shown continued robust progress since the RTI study was conducted. At the time the analysis of the company for this mini-study was completed in 1999, company employment had increased four-fold, and a recent check showed another big increase. Through its commercial partners, Integra's technology is becoming embodied in surgical screws, tacks, and other fixation devices for attaching soft tissue to bone in the knee and shoulder. Pending FDA approval, patients are positioned to benefit in terms of complications and further surgeries avoided, as well as from lower surgical costs.

Stem Cell Expansion

Because of the difficulty of estimating the value of patient pain reduction and improved health outcomes, the RTI study also based the benefits estimates for Aastrom's stem cell expansion technology only on the reduction in procedure cost, although these former effects are the main expected feature of this technology. RTI economists estimated that the replication system, once implemented, would save about $87 million (in 1997 dollars) in the costs of providing bone-

[16] The estimate, which was net of costs, did not include benefits of patient health effects and pain-avoided.

marrow transplants for cancer treatment without the acceleration provided by ATP support and $134 million with the acceleration. The difference, $47 million, is the estimated additional value, in terms of cost savings only, attributed to the ATP, based on this application area. Aastrom, the award recipient, has since continued unabated pursuit of the commercialization of its AastromReplicall™ System. In recent clinical trials, the system was used successfully to enable cancer patients for which there were otherwise no donors to receive stem cell transplants. According to the director of medical oncology at Hackensack University Medical Center, "These results suggest that we may have found a new treatment approach that will enable more patients to receive treatment for this very serious and often fatal disease."[17] According to the American Cancer Society, 30,000 new cases of leukemia are expected in 2000 and approximately 20,000 people will die from the disease this year. More effective treatments able to reduce this toll would be of great value to society.

Repairing Knees

Focusing on the first expected application of Tissue Engineering's ADMAT technology, namely, the repair of damaged knee ligaments (specifically, anterior cruciate ligaments, or ACLs), RTI economists also estimated benefits. But in this case, unlike the previous two, RTI was able to estimate benefits expected to result from improvements in the quality of life for patients receiving the treatment, by using a "quality-adjusted-life-years" index value.[18] RTI estimated about $15 billion in expected net benefits from the new technology attributable to ATP funding.

Printed Wiring Board

Another of the top performing projects is a joint venture led by the National Center for Manufacturing Sciences (NCMS) to develop a suite of advanced technologies for producing printed wiring boards (PWBs), the backbones of electronics products. Two studies conducted by Professor Albert Link of the University of North Carolina-Greensboro, focused on assessing the impact of the project's extensive use of collaborative effort.[19] The studies estimated that the project's collaborative effort produced at least a 53 percent reduction in overall research costs, resulting in an R&D savings of at least $35.5 million, in the process of producing new capabilities that the industry needed for international competitive-

[17] PRNewswire, 19 April 2000, report on results from Hackensack/Aastrom Studies.

[18] For a description of the use of Quality-Adjusted Life-Years (QALY) in evaluating patient benefits in evaluation studies, see A. J. Wang, "Key Concepts in Evaluating Outcomes of ATP Funding of Medical Technologies," *The Journal of Technology Transfer*, 23(2):61-66.

[19] For a more detailed treatment see A. N. Link "Enhanced R&D Efficiency in an ATP-funded Joint Venture," in this volume.

ness. The project has yielded productivity improvements for member companies and improved competitive positions of U.S. suppliers in the world market for PWBs.[20] Award-winning papers, new products, and other knowledge dissemination activities by the joint venture has helped to spread the new capabilities across the entire industry. At a recent technology exposition by ATP-funded companies, an advanced circuit board was displayed that incorporated many of the innovations developed by the ATP-funded project. A small company, one that did not participate directly in the project, produced it, suggesting the flow of knowledge from the project to others.[21]

Improved Software to Process High-volume Data

Another of the top performers is a project led by Torrent Systems, Inc., which has developed a component software system that insulates programmers from the complexities of parallel programming while allowing them to use it productively in scalable applications. Torrent delivered this new capability in its software product, Orchestrate™. An early company user of the new software reportedly was able to increase its revenue by $100 million per year.[22] Torrent's technology is making it possible for eBusinesses and other companies to process and analyze great volumes of data. In addition to receiving a number of other awards recognizing its software technology, Torrent was listed in ComputerWorld's "100 Hot Emerging Companies" in 1998.

High-Temperature Superconducting Wire

American Superconductor Corporation, who led another of the top performing projects, is producing high-temperature superconducting wire for use by electric utilities and as a component in motors, transformers, and specialty magnets to reduce their energy consumption. With an estimated sales volume of $15 million in 2000, and a rapid sales growth rate, this small company is commercializing its technology. The technology's ability to reduce energy costs has taken on increased significance in the face of rising energy prices.

Improved Medical Procedures

Like the preceding examples, Engineering Animation, Inc., leader of another of the top performing projects, has aggressively and successfully pursued appli-

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[20] The president of NCMS credited the ATP project with saving the PWB industry in the U.S. with its approximately 200,000 jobs.

[21] ATP Technology Showcase, "Ten Years of Innovation and Impact," discussions with an NCMS spokesperson, hosted by the Advanced Technology Program, Washington, D.C.: Russell Senate Building, Caucus Room, 5 April 2000.

[22] Information from Hoover's on-line company search and Torrent's web site, current 31 August 2000.

cations of its award-winning imaging software capabilities developed in the ATP-funded project. The company used its ATP-funded technology to improve the training of doctors, as well as to guide medical procedures. Patients in a particular surgical procedure that employed the company's visualization software reportedly had better outcomes as a result. Founded by two professors and two graduate students in 1990, the company had 20 employees at the time it received the ATP award. The company now employs approximately 1,000, had sales of $71 million in 1999, and experienced a sales growth rate over the past year of 34 percent. According to company officials, the ATP award allowed it to significantly extend its capabilities in computer visualization and computations dynamics and to form important collaborative relationships that it has since been able to leverage in many different directions. Recently, it has extended and deployed its award-winning visualization capabilities to develop a virtual factory technology, implemented recently at Ford, which enables faster design and analysis of factory models. Its many customers and clients have in turn benefited.

Better Auto Bodies

To these examples, we can add a number of other strong projects from among the 50 that produced technologies that are delivering important benefits. One such project, led by the Auto Body Consortium, has generated documented production cost savings and improved automobile quality, as well as the potential for extending these same kinds of benefits to the manufacturing assembly of other products. A study by the CONSAD Research Corporation attributed economy-wide benefits of about $3 billion in the year 2000 to the project.[23]

…and Better Enzymes

Another example is provided by a project led by Amersham Pharmacia Biotech, which is credited with accelerating development of an enzyme important to the speed of the human genome project—where timing is of enormous significance. To these examples, we can also add a number of other promising technologies—technologies that may improve productivity, facilitate better weather forecasts, improve communications, enable new drug discovery, reduce energy costs, and lower loss of limb and life globally by improving detection of old land mines and toxins.

[23] CONSAD Research Corporation, *Advanced Technology Program Case Study: The Development of Advanced Technologies and Systems for Controlling Dimensional Variation in Automobile Body Manufacturing*, NIST GCR 97-709, March 1997. A new study is currently underway, led by MIT researchers, to extend and update the analysis of this project. Contact ATP's Economic Assessment Office for further information.

WHAT CONSTITUTES SUCCESS AND FAILURE FOR ATP?

Because individual-project failure must be anticipated and tolerated in a program that focuses on overcoming challenging technical barriers to innovation, it is essential to take a project-portfolio approach to assessing the ATP against the legislated mission of the program.

Three general tests, and several additional specific tests—all derived from ATP's mission—if applied after sufficient passage of time, should reveal the extent to which ATP has successfully met its mission:[24]

- Test 1: Has the portfolio of ATP-funded projects overall produced large net benefits (i.e., benefits minus costs) for the nation?
- Test 2: Have a substantial share of the net national benefits accrued to citizens and organizations beyond the ATP-award recipients?
- Test 3: Did ATP make a substantial positive difference in the size and timing of the benefits?

Additional specific tests of success include the following: Did the projects produce new scientific and technical knowledge? Did the ATP increase collaboration? Were small businesses able to participate? Were manufacturing capabilities improved? Did U.S. businesses become better able to compete in global markets?

Partial Answers

While the ultimate answers to these success "test questions" depend on the long-run impacts of the portfolio of ATP projects, the performance-to-date of the sub-portfolio of 50 projects provides partial answers of considerable interest.

The performance ratings show that the majority of the projects are still underway, and further progress continues to be made. More importantly, they reveal a core group of highly active and productive performers, albeit a minority, who are successfully accomplishing the big goals of their projects.

The ATP awarded a total of $104.0 million to the 50 completed projects. What is the public investment producing in the way of benefits? The ATP's impact appears to be substantial from the perspective of economic return on the government expenditure (i.e., the cost of the award), the catalytic effect of the award (i.e., its ability to bring technology forward and leverage previous funding), and through the substantial downstream positive spillovers or benefits to others.

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[24] The tests of success are taken from a presentation by Rosalie T. Ruegg before the National Grants Management Association's Annual Conference, Federal Bar Association Panel, 4 April 2000.

Economic Returns

Estimated quantifiable economic benefits attributed to the ATP from just a few of the top performing 50 projects not only greatly exceed ATP's funding for all of the 50 projects, they also far exceed the total of ATP costs for all of the 522 projects funded to date.

Catalytic Effects

Detailed case studies and extensive interviews with the project leaders attributed to ATP a key role in bringing the projects to fruition or in accelerating their development.

Social Benefits

In addition to benefits exceeding costs, there is strong evidence that benefits are extending well beyond those captured by the award recipients. There is substantial evidence that the knowledge generated by the projects is being disseminated through publications, presentations, patents, products, and other means. The patent trees developed for these projects reveal rich citations of the patents by others. The products and processes generated by the projects are also yielding benefits extending beyond project participants. For example, patients are receiving spillover benefits from new, better medical treatments available at lower costs; consumers are receiving spillover benefits when they buy superior products for which they pay less than the full value; and companies outside the projects are receiving spillovers when they increase their productivity or achieve greater value added by using ATP-funded technologies.

These answers are, as we underscore, partial in nature. More time is necessary for a fuller assessment. Over time, a fuller assessment should reveal wider diffusion of some technologies, the demise of others, perhaps many others, and major success from a few. What this research does show is that the program is achieving its goals for a significant number of awards. It also highlights the research and measurement efforts of a program able and willing to document its failures as well as its successes. The failures in part offer reassuring evidence that the program continues to pursue its mandate of investing in high-risk, but potentially high-payoff, technologies with gains for participants and for society.

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VI

ANNEX

Annex A:

Authorizing Legislation for the Advanced Technology Program

US Code as of: 01/23/00

Omnibus Trade and Competitiveness Act, 1988
Legislation Authorizing the Advanced Technology Program

§ 278n. Advanced Technology Program

(a) Establishment; purpose; focus; guidance

There is established in the Institute an Advanced Technology Program (hereafter in this chapter referred to as the "Program") for the purpose of assisting United States businesses in creating and applying the generic technology and research results necessary to -

(1) commercialize significant new scientific discoveries and technologies rapidly; and

(2) refine manufacturing technologies. The Secretary, acting through the Director, shall assure that the Program focuses on improving the competitive position of the United States and its businesses, gives preference to discoveries and to technologies that have great economic potential, and avoids providing undue advantage to specific companies. In operating the Program, the Secretary and Director shall, as appropriate, be guided by the findings and recommendations of the Biennial National Critical Technology Reports prepared pursuant to section 6683 of title 42.

(b) Authority of Secretary; research and development; contracts and cooperative agreements; Federal laboratories; other activities with joint ventures

Under the Program established in subsection (a) of this section, and consistent with the mission and policies of the Institute, the Secretary, acting through the Director, and subject to subsections (c) and (d) of this section, may -

(1) aid industry-led United States joint research and development ventures (hereafter in this section referred to as "joint ventures") (which may also include universities and independent research organizations), including those involving collaborative technology demonstration projects which develop and test prototype equipment and processes, through -

(A) provision of organizational and technical advice; and
(B) participation in such joint ventures by means of grants, cooperative agreements, or contracts, if the Secretary, acting through the Director, determines participation to be appropriate, which may include
(i) partial start-up funding,
(ii) provision of a minority share of the cost of such joint ventures for up to 5 years, and
(iii) making available equipment, facilities, and personnel, provided that emphasis is placed on areas where the Institute has scientific or technological expertise, on solving generic problems of specific industries, and on making those industries more competitive in world markets;

(2) provide grants to and enter into contracts and cooperative agreements with United States businesses (especially small businesses), provided that emphasis is placed on applying the Institute's research, research techniques, and expertise to those organizations' research programs;
(3) involve the Federal laboratories in the Program, where appropriate, using among other authorities the cooperative research and development agreements provided for under section 3710a of this title; and
(4) carry out, in a manner consistent with the provisions of this section, such other cooperative research activities with joint ventures as may be authorized by law or assigned to the Program by the Secretary.

(c) Authority of Secretary; selection criteria; monitoring use of technologies; overseas transfer; annual report to Congress; financial reporting and auditing; routine consideration of Committee advice; dissemination of research results

The Secretary, acting through the Director, is authorized to take all actions necessary and appropriate to establish and operate the Program, including -

(1) publishing in the Federal Register draft criteria and, no later than six months after August 23, 1988, following a public comment period, final criteria, for the selection of recipients of assistance under subsection (b)(1) and (2) of this section;
(2) monitoring how technologies developed in its research program are used, and reporting annually to the Congress on the extent of any overseas transfer of these technologies;
(3) establishing procedures regarding financial reporting and auditing to ensure that contracts and awards are used for the purposes specified in this section, are in accordance with sound accounting practices, and are not funding existing or planned research programs that would be conducted in the same time period in the absence of financial assistance under the Program;

(4) assuring that the advice of the Committee established under section 278 of this title is considered routinely in carrying out the responsibilities of the Institute; and

(5) providing for appropriate dissemination of Program research results.

(d) Contracts or awards; criteria; restrictions

When entering into contracts or making awards under subsection (b) of this section, the following shall apply:

(1) No contract or award may be made until the research project in question has been subject to a merit review, and has, in the opinion of the reviewers appointed by the Director and the Secretary, acting through the Director, been shown to have scientific and technical merit.

(2) In the case of joint ventures, the Program shall not make an award unless the award will facilitate the formation of a joint venture or the initiation of a new research and development project by an existing joint venture.

(3) No Federal contract or cooperative agreement under subsection (b)(2) of this section shall exceed $2,000,000 over 3 years, or be for more than 3 years unless a full and complete explanation of such proposed award, including reasons for exceeding these limits, is submitted in writing by the Secretary to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives. The proposed contract or cooperative agreement may be executed only after 30 calendar days on which both Houses of Congress are in session have elapsed since such submission. Federal funds made available under subsection (b)(2) of this section shall be used only for direct costs and not for indirect costs, profits, or management fees of the contractor.

(4) In determining whether to make an award to a particular joint venture, the Program shall consider whether the members of the joint venture have made provisions for the appropriate participation of small United States businesses in such joint venture.

(5) Section 552 of title 5 shall not apply to the following information obtained by the Federal Government on a confidential basis in connection with the activities of any business or any joint venture receiving funding under the Program -

(A) information on the business operation of any member of the business or joint venture; and

(B) trade secrets possessed by any business or any member of the joint venture.

(6) Intellectual property owned and developed by any business or joint

venture receiving funding or by any member of such a joint venture may not be disclosed by any officer or employee of the Federal Government except in accordance with a written agreement between the owner or developer and the Program.

(7) If a business or joint venture fails before the completion of the period for which a contract or award has been made, after all allowable costs have been paid and appropriate audits conducted, the unspent balance of the Federal funds shall be returned by the recipient to the Program.

(8) Upon dissolution of any joint venture or at the time otherwise agreed upon, the Federal Government shall be entitled to a share of the residual assets of the joint venture proportional to the Federal share of the costs of the joint venture as determined by independent audit.

(9) A company shall be eligible to receive financial assistance under this section only if -

(A) the Secretary finds that the company's participation in the Program would be in the economic interest of the United States, as evidenced by investments in the United States in research, development, and manufacturing (including, for example, the manufacture of major components or subassemblies in the United States); significant contributions to employment in the United States; and agreement with respect to any technology arising from assistance provided under this section to promote the manufacture within the United States of products resulting from that technology (taking into account the goals of promoting the competitiveness of United States industry), and to procure parts and materials from competitive suppliers; and

(B) either -

(i) the company is a United States-owned company; or

(ii) the Secretary finds that the company is incorporated in the United States and has a parent company which is incorporated in a country which affords to United States-owned companies opportunities, comparable to those afforded to any other company, to participate in any joint venture similar to those authorized under this chapter; affords to United States-owned companies local investment opportunities comparable to those afforded to any other company; and affords adequate and effective protection for the intellectual property rights of United States-owned companies.

(10) Grants, contracts, and cooperative assignments under this section shall be designed to support projects which are high risk and which have the potential for eventual substantial widespread commercial application. In order to receive a grant, contract, or cooperative agree-

ment under this section, a research and development entity shall demonstrate to the Secretary the requisite ability in research and technology development and management in the project area in which the grant, contract, or cooperative agreement is being sought.

(11)

(A) Title to any intellectual property arising from assistance provided under this section shall vest in a company or companies incorporated in the United States. The United States may reserve a nonexclusive, nontransferable, irrevocable paid-up license, to have practiced for or on behalf of the United States, in connection with any such intellectual property, but shall not, in the exercise of such license, publicly disclose proprietary information related to the license. Title to any such intellectual property shall not be transferred or passed, except to a company incorporated in the United States, until the expiration of the first patent obtained in connection with such intellectual property.

(B) For purposes of this paragraph, the term "intellectual property" means an invention patentable under title 35 or any patent on such an invention.

(C) Nothing in this paragraph shall be construed to prohibit the licensing to any company of intellectual property rights arising from assistance provided under this section.

(e) Suspension for failure to satisfy eligibility criteria

The Secretary may, within 30 days after notice to Congress, suspend a company or joint venture from continued assistance under this section if the Secretary determines that the company, the country of incorporation of the company or a parent company, or the joint venture has failed to satisfy any of the criteria set forth in subsection (d)(9) of this section, and that it is in the national interest of the United States to do so.

(f) Coordination with other Federal technology programs

When reviewing private sector requests for awards under the Program, and when monitoring the progress of assisted research projects, the Secretary and the Director shall, as appropriate, coordinate with the Secretary of Defense and other senior Federal officials to ensure cooperation and coordination in Federal technology programs and to avoid unnecessary duplication of effort. The Secretary and the Director are authorized to work with the Director of the Office of Science and Technology Policy, the Secretary of Defense, and other appropriate Federal officials to form interagency working groups or special project offices to coordinate Federal technology activities.

(g) Meetings with industry sources

In order to analyze the need for the value of joint ventures and other research projects in specific technical fields, to evaluate any proposal made by a joint venture or company requesting the Secretary's assistance, or to monitor the progress of any joint venture or any company research project which receives Federal funds under the Program, the Secretary, the Under Secretary of Commerce for Technology, and the Director may, notwithstanding any other provision of law, meet with such industry sources as they consider useful and appropriate.

(h) Standards development

Up to 10 percent of the funds appropriated for carrying out this section may be used for standards development and technical activities by the Institute in support of the purposes of this section.

(i) Acceptance of funds from other Federal departments and agencies

In addition to such sums as may be authorized and appropriated to the Secretary and Director to operate the Program, the Secretary and Director also may accept funds from other Federal departments and agencies for the purpose of providing Federal funds to support awards under the Program. Any Program award which is supported with funds which originally came from other Federal departments and agencies shall be selected and carried out according to the provisions of this section.

(j) Definitions

As used in this section -

(1) the term "joint venture" means any group of activities, including attempting to make, making, or performing a contract, by two or more persons for the purpose of -

(A) theoretical analysis, experimentation, or systematic study of phenomena or observable facts;

(B) the development or testing of basic engineering techniques;

(C) the extension of investigative finding or theory of a scientific or technical nature into practical application for experimental and demonstration purposes, including the experimental production and testing of models, prototypes, equipment, materials, and processes;

(D) the collection, exchange, and analysis of research information;

(E) the production of any product, process, or service; or

(F) any combination of the purposes specified in subparagraphs (A), (B), (C), (D), and (E), and may include the establishment and operation of facilities for the conducting of research, the conducting of such venture on a protected and proprietary basis, and the prosecuting of applications for patents and the granting of licenses for the results of such venture; and

(2) the term "United States-owned company" means a company that has majority ownership or control by individuals who are citizens of the United States.

Annex B:

Biographies of Contributors *

DAVID AUSTIN

David Austin is a fellow in Resources for the Future's (RFF) Quality of the Environment division. He joined RFF in 1993. Dr. Austin's research interests include the welfare effects of innovation; corporate environmental performance and public policy; technology and transportation modeling; and integrated assessment of environmental costs and benefits.

His recent work includes the development of a quality-adjusted cost index method for estimating future returns from innovation. The index permits estimation of private and public economic benefits of technology-driven services—in the renewable energy, information, and space exploration sectors—for which consumer demand is not directly observable. This work has implications for efficient R&D resource allocation, both in the public and private sectors.

Dr. Austin is also currently studying private incentives for firms to improve their environmental performance. His recent, co-authored econometric studies of state environmental liability policy indicate that states in the U.S. have tended to adopt strict liability policies in response to perceived problems with chemical spills and accidents, and that these policies have resulted in fewer spills. Currently he is examining firm-level data on environmental performance and profitability for thus-far elusive evidence of causality. This research addresses the belief by some in the environmental policy community that many firms have failed to recognize the profit potential in reducing their emissions.

* As of February 2001. Biographies were submitted for inclusion by the authors of the papers.

His work in transportation economics centers on travel-demand forecasting as a vehicle for studying the potential of Intelligent Transportation Systems technologies, and congestion-pricing policies to reduce highway congestion and improve welfare. Austin has also recently helped initiate a study of the economic implications of potential policies toward utility-generated mercury emissions, including the posting of fish advisories. With this work, he again takes up the modeling of aquatic effects of atmospheric pollutant deposition, for which he developed a detailed, integrated-assessment model of Maryland's principal aquatic ecosystems.

His work has been published in *The American Economic Review*, the *Journal of Regulatory Economics*, the *Journal of Environmental Economics and Management*, and *Contemporary Economic Policy*, among others.

Dr. Austin is a member of the Association of Environmental and Resource Economists. He received his Bachelor's degree in mathematics from Stanford University, his Master's degree in statistics from Yale University, and his Ph.D. in economics from the University of California at Berkeley.

ALAN P. BALUTIS

Alan Balutis is the Director of the Advanced Technology Program. He came to Washington in 1975 as a National Association of Schools of Public Affairs and Administration (NASPAA) Fellow. He worked in a variety of budget, personnel, policy and legislation, and management analysis positions at the then-Department of Health, Education and Welfare (HEW) before coming to the Department of Commerce in 1979. At HEW, he was a member of a small staff assembled to implement major Departmental reorganization, involving several programs with a combined budget of over $52 billion and more than 10,000 employees.

Prior to coming to Washington, he served as an Assistant Professor of Political Science at the State University of New York at Buffalo and worked with the New York State Legislature and the National Conference of State Legislatures. He is the author or co-author of four books, over 100 articles, and numerous conference papers on government reorganization, legislative reform, budgeting, and internship programs.

In the Department of Commerce, he worked as Director, Office of Systems and Special Projects (1983-84), as Director, Office of Management and Organization (1984-87), as Director for Budget, Management, and Information (1987-98), and as Deputy Chief Information Officer (1998-2000), where he was responsible for Information Technology (IT) and oversight of total expenditures of $1.1 billion and created the first major systems oversight board in the government. In April 2000, he was appointed Director of the Advanced Technology Program at the National Institute of Standards and Technology.

An active member of the newly established CIO Council, he headed their Strategic Planning Committee and the Outreach Committee. He currently co-chairs the Electronic Government Committee.

He was the first recipient of the Annual Commerce Award for Outstanding Management and received the Silver Medal (1983) and the Gold Medal (1986)—the Department's two highest honors. He also is a recipient of two Presidential rank awards (1988 and 1995) and has been named for four years in a row to the Federal 100 by Federal Computer Week as a major player in the IT community. In 1998, he was elected as a Fellow of the National Academy of Public Administration.

TAYLER H. BINGHAM

Tayler Bingham is Director of Research Triangle Institute's Center for Regulatory Economics and Policy Research, which conducts research related to environmental and natural resources, food, and new technologies. The Center employs microeconomic, financial, technical modeling using interdisciplinary frameworks; primary data collection and analysis; and benefit-cost, cost-effectiveness, and economic impact analyses to evaluate alternative public policies. Mr. Bingham has evaluated both traditional administrative regulations and innovative economic instruments such as fees and transferable permits designed to protect or improve the quality of the environment and promote the sustainable management of natural resources. He has also contributed to analyses of the potential of new technologies to contribute to economic welfare, modeling technology diffusion and valuing the social benefits and costs of the technologies employing microeconomic methods and applied welfare economics principles. Mr. Bingham is a member of the American Economic Association. He is also a member of the Association of Environmental and Resource Economists and has served on its Board of Directors and participated in association activities. He authored a chapter on environmental benefits valuation and has published papers in the *Journal of Environmental Economics and Management* and *Public Finance Quarterly*. He has taught microeconomic theory and environmental economics at North Carolina State University and environmental economics at Duke University.

JEFFREY H. DYER

Jeffrey Dyer is Associate Professor and Donald Staheli Chair in International Strategy at Brigham Young University. He previously served on the faculty at the University of Pennsylvania's Wharton School. His research interests include strategic alliances and international joint ventures; interorganizational learning and knowledge management; and interorganizational trust.

Dr. Dyer is the author of a number of articles published in journals such as *Harvard Business Review*, *Strategic Management Journal*, *Academy of Management Review,* and *California Management Review*. He is the author of the book *Collaborative Advantage*, recently published by Oxford University Press. He has been awarded the McKinsey/Strategic Management Society Best Paper Prize, and the University-wide undergraduate Teaching Award and other MBA excellence in teaching awards at the University of Pennsylvania.

Dr. Dyer holds a Ph.D. in management from the University of California, Los Angeles, and an MBA from Brigham Young University.

Jeffrey Dyer's co-author, Benjamin C. Powell, is a Ph.D. candidate in the Management Department at the Wharton School, University of Pennsylvania. He holds an M.A. from the University of Pennsylvania in Applied Economics and Managerial Science and an MBA from the Kenan-Flagler Business School, University of North Carolina, Chapel Hill. Mr. Powell's six years of professional experience includes working for Milliken & Company's alliance with TRW to develop air bag fabrics and work as a consultant with Heiniburg Corporation setting up automotive joint ventures in Thailand.

MARYANN P. FELDMAN

Maryann P. Feldman is Research Scientist at the Institute for Policy Studies and Associate Professor of Economics at Johns Hopkins University. She received her B.A. from Ohio State University, and her Ph.D. from Carnegie Mellon University. She previously taught economics at Western Maryland College and Goucher College. Before coming to Hopkins, she was on the faculty at the H.J. Heinz School at Carnegie Mellon.

Dr. Feldman is the author of over thirty academic articles that have been published in such journals as *The American Economic Review, The Review of Economics and Statistics,* and *The Annals of the Association of American Geographers.* Her Ph.D. dissertation, *The Geography of Innovation,* was published in 1994 by Kluwer Academic Publishers and is now in its second printing. She edited *The Handbook of Economic Geography* for Oxford University Press (with Gordon Clark and Meric Gertler), published in 2000. Forthcoming books include *Innovation Policy for A Knowledge-Based Economy* (with Al Link) and *Institutions and Systems in the Geography of Innovation* (with Nadine Massard).

Dr. Feldman has also served as a consultant to private business, various federal, state and local agencies and non-profit organizations. She has received grants from the National Science Foundation, the Mellon Foundation, the National Institute of Standards and Technology, the German Marshall Fund, and the U.S. Small Business Administration, among others. She is an author of the 1998 monograph *Biosciences in Maryland: A Closer Look* as well as "Role of the Department of Defense in Building Biotech Expertise" in the 2000 National Research Council report, *The Small Business Innovation Research Program: An Assessment of the Department of Defense Fast Track Initiative.*

MARYELLEN R. KELLEY

Maryellen R. Kelley is the Principal Partner at Pamet Hill Associates, a consulting firm that provides business planning and program evaluation services to firms and to R&D programs of government agencies. She was Senior Economist in the Economic Assessment Office of the Advanced Technology Program (ATP) at the National Institute of Standards and Technology from 1997-2000. Prior to her service at the ATP, Dr. Kelley was on the faculty of Carnegie Mellon University. She also held faculty and research appointments at Harvard University, the Massachusetts Institute of Technology, and the University of Massachusetts. She received her B.A. from Brandeis University, a Masters degree from Harvard University in City and Regional Planning, and a Ph.D. in management from the Massachusetts Institute of Technology. She has published extensively on economic, management, and policy issues concerning technological change, in such journals as *The American Sociological Review*, *Economic Development Quarterly, Management Science*, *Research Policy*, and *Science*.

BARBARA LAMBIS

Barbara Lambis is the Senior Policy and Operations Advisor to the Director, Advanced Technology Program (ATP) at the National Institute of Standards and Technology (NIST). Ms. Lambis is the key focal point for providing policy and administrative guidance to the ATP and the general public. She is responsible for formulating policies and procedures, developing and implementing regulations, and providing operational guidance to the ATP. She serves as program liaison with the Office of General Counsel, Office of Inspector General, General Accounting Office, and the Office of Management and Budget.

Ms. Lambis has worked at the Department of Commerce since 1969. Prior to coming to NIST in 1994, Ms. Lambis was the Director, Office of Federal Assistance, Department of Commerce (DoC). Ms. Lambis was responsible for grant and cooperative agreement-related policy development and implementation for the DoC and was a Grants Officer. She served as a senior consultant to top level staff of DoC operating units and the Office of the Secretary in grants administration matters. Ms. Lambis also worked at the National Oceanic and Atmospheric Administration, DoC, performing grants management activities.

Ms. Lambis earned a B.A. degree in english from the University of Maryland. She has received numerous awards and citations at the Department of Commerce, including the Award for Outstanding Administrative Management and Employee of the Year Award (Management/Supervisory).

ALBERT N. LINK

Albert N. Link is Professor of Economics at the University of North Carolina at Greensboro. He received his B.S. in mathematics from the University of Richmond in 1971 and his Ph.D. in economics from Tulane University in 1976. Prior to joining the faculty at the University of North Carolina at Greensboro in 1982, he was on the faculty at Auburn University and was scholar in residence at Syracuse University.

Professor Link's research focuses broadly on the economics of science and technology policy. His publications encompass many dimensions of that field ranging from philosophy of science to the mathematical theory of productivity growth. More specifically, Professor Link has written extensively on methods for evaluating public sector and private sector research and development, technology policies to promote economic growth, and corporate strategies to increase competitiveness.

Professor Link has served on data and evaluation advisory panels of the National Academy of Sciences, the National Science Foundation, the OECD, and other government agencies such as NASA and the National Institute of Standards and Technology. He has also consulted for numerous European Union and APEC governments on science policy and program evaluation.

Among his most recent books are *Public Accountability: Evaluating Technology-Based Institutions* (with John T. Scott), *A Generosity of Spirit: The Early History of Research Triangle Park*, and *Evaluating Public Sector Research and Development*. His scholarly papers have appeared in such journals as the *Journal of Political Economy*, *American Economic Review*, *Research Policy*, *STI Review*, and the *International Journal of Industrial Organization*.

Professor Link is also the editor of the international *Journal of Technology Transfer*.

MOLLY MACAULEY

Molly Macauley is a senior fellow in the Energy and Natural Resources division. She also directs RFF's academic programs, which includes the RFF Wednesday Seminar Series and a number of fellowship and internship programs. Her research interests include: space economics and policy; the economics of new technologies; recycling and solid waste management; urban transportation policy; and the use of economic incentives in environmental regulation.

An economist at RFF since 1983 and a long-time analyst of the commercial use of space technology, Dr. Macauley offered her views to Congress in May 1997 on how government can foster burgeoning commercial ventures into satellite remote sensing. She has recently been nominated by the National Research Council to serve as a member of the Committee on an Assessment of the National Aeronautics and Space Administration's Space Solar Power Investment Strategy. One of her major research projects looks at the ongoing economic, privacy, security, and other implications of American companies selling images photographed by privately owned satellites in outer space. She was also appointed to a two-year term on a National Research Council Study of this topic. She has also been appointed to the National Aeronautics and Space Administration's Space Science

Advisory Committee, and currently serves on the Board of Directors of Women in Aerospace.

Dr. Macauley's other research projects are exploring the use of economic incentives to manage space debris; the allocation of scarce energy, water, utilities and telecommunications resources on the space station; the value of geostationary orbit; the value of information, particularly information derived from space-based remote sensing; and the estimation of returns to investing in R&D. Dr. Macauley was named by the National Space Society as one of the top 25 "rising stars" among people doing work related to the U.S. space program. She received her Ph.D. in economics from Johns Hopkins University.

ROSALIE RUEGG

Since May 2000, Rosalie Ruegg has headed Technology Impact Assessment (TIA) Consulting, a small company that provides economics and business consulting to government and business clients. Over the past decade, she guided the development of the Advanced Technology Program's impact evaluation, as director of the Office of Economic Assessment. Other positions she has held include Senior Staff Advisor to the Associate Director of the National Engineering Laboratory of the National Institute of Standards and Technology (NIST); Research Economist in NIST's Applied Mathematics Laboratory; Financial Economist with the Board of Governors of the Federal Reserve System; and Course Designer and Instructor for universities, government agencies, and a private company. She is co-author of a textbook in economics and instructional videos on benefit-cost, life-cycle cost and risk analyses, the author of more than 60 reports, papers, and book chapters, and economics editor of a new energy encyclopedia. Ms. Ruegg graduated with honors from the University of North Carolina, where she was a member of Phi Beta Kappa. She received advanced degrees in economics and business from the University of Maryland, as a Woodrow Wilson Fellow, and from The American University (MBA, specialty in finance). A member of the Federal Senior Executive Service, she received Gold and Silver Medals for excellence from the U.S. Department of Commerce, the highest awards bestowed by the Department. Ms. Ruegg has extensive executive and leadership training.

Annex C:

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Annex D:

Internal and External Reviews of the ATP, Analyses Commissioned by the Office of Economic Assessment

PUBLISHED PAPERS AND REPORTS

Austin, David and Molly Macauley. 2000. *Estimating Future Consumer Benefits from ATP-Funded Innovation: The Case of Digital Data Storage.* NIST GCR 00-790. April.

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Annex E:

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